Development of Bacterial TMDLs for the Virginia Beach Coastal Area

(London Bridge Creek & Canal # 2, Milldam Creek, Nawney Creek, West Neck Creek (Middle), and West Neck Creek (Upper))

Prepared for:

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CONTENTS

FIGURES

TABLES

ACKNOWLEDGEMENTS

Virginia Department of Environmental Quality (VADEQ), Central Office

VADEQ Tidewater Regional Office

Virginia Department of Conservation and Recreation (VADCR)

Natural Resources Conservation Service

Virginia Beach Agriculture Agency

Virginia Cooperative Extension Service

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EXECUTIVE SUMMARY

Background and Applicable Standards

The Virginia Beach Coastal Study Area includes portions of the following U.S.G.S. hydrologic units:

1. Albemarle (03010205)
2. Lynnhaven-Poquoson (02080108)

The Albemarle watershed contains the impaired segments of Nawney Creek, which drains to Back Bay, and Milldam Creek and West Neck Creek (middle), which both drain to the North Landing River. The Albemarle watershed includes portions of Virginia Beach City and Chesapeake City; the upper portion of West Neck Creek has recently (2004) been moved from the Albemarle watershed to the Lynnhaven-Poquoson watershed, as West Neck Creek drains to London Bridge Creek. The London Bridge Creek and Canal #2 impairment is in the Lynnhaven-Poquoson watershed, and drains to the Lynnhaven Bay.

Nawney Creek was initially placed on the *Virginia 1996 Section 303(d) TMDL Priority List and Report* based on monitoring performed. Additional stream segments within the Virginia Beach Coastal Study Area were successively placed on the *Virginia 1998 Section 303(d) Total Maximum Daily Load Priority List and Report* and the *Virginia 2002 Section 303(d) Report on Impaired Waters*. All segments remained on the *Virginia 2004 Section 305(b)/303(d) Water Quality Integrated Report*.

Prior to 2003, Virginia Water Quality Standards specified the following criteria for a non-shellfish supporting waterbody to be in compliance with Virginia's fecal standard for contact recreational use:

> *A. General requirements. In all surface waters, except shellfish waters and certain waters addressed in subsection B of this section, the fecal coliform bacteria shall not exceed a geometric mean of 200 fecal coliform bacteria per 100 ml of water for two or more samples over a 30-day period, or a fecal coliform bacteria level of 1,000 per 100 ml at any time.*

The EPA has since recommended that all states adopt an *E. coli* or *enterococci* standard for fresh water and *enterococci* criterion for marine waters by 2003. Virginia's new standard went into effect January 15, 2003.

The new criteria, outlined in 9 VAC 25-260-170, read as follows

> *A. In surface waters, except shellfish waters and certain waters identified in subsection B of this section, the following criteria shall apply to protect primary contact recreational uses:*
>
> *1. Fecal coliform bacteria shall not exceed a geometric mean of 200 fecal coliform bacteria per 100 ml of water for two or more samples over a calendar month nor shall more than 10% of the total samples taken during any calendar month exceed 400 fecal coliform bacteria per 100 ml of water. This criterion shall not apply for a sampling station after the bacterial indicators described in subdivision 2 of this subsection have a minimum of 12 data points or after June 30, 2008, whichever comes first.*
>
> *2. E. coli and enterococci bacteria per 100 ml of water shall not exceed the following:*

	Geometric Mean[1]	*Single Sample Maximum*[2]
Freshwater[3]*E. coli*	*126*	*235*
Saltwater and Transition Zone[3] *Enterococci*	*35*	*104*

[1] For two or more samples taken during any calendar month.

[2] No single sample maximum for e*nterococci* and *E. coli* shall exceed a 75% upper one-sided confidence limit based on a site-specific log standard deviation. If site data are insufficient to establish a site-specific log standard deviation, then 0.4 shall be used as the log standard deviation in freshwater and 0.7 shall be as the log standard deviation in saltwater and transition zone. Values shown are based on a log standard deviation of 0.4 in freshwater and 0.7 in saltwater.

[3] See 9 VAC 25-260-140 C for freshwater and transition zone delineation.

These criteria were used in developing the bacteria TMDLs included in this study.

TMDL Endpoint and Water Quality Assessment

Potential sources of fecal coliform include both point source and nonpoint source contributions. Nonpoint sources include: wildlife; grazing livestock; land application of manure; land application of biosolids; urban/suburban runoff; failed and malfunctioning septic systems; and uncontrolled discharges (*i.e*. dairy parlor waste, etc.). There are two

MS4 (Municipal Storm Water) permits issued to the City of Virginia Beach (VA0088676) and the U.S. Naval Air Station at Oceana (VAR040043). MS4 discharges are expected to contain measurable amounts of fecal coliform but have no treatment or monitoring requirements.

The *E. coli* bacteria standard specifies that the number of *E. coli* bacteria shall not exceed a maximum allowable level of 235-cfu /100 ml. Similarly, the *enterococci* standard states that no single sample shall exceed 104-cfu/100 ml (Virginia Water Quality Standard 9 VAC 25-260-170). In addition, if data is available, the geometric mean of two or more observations taken in a calendar month should not exceed 126-cfu/100 ml *E. coli*, or 35-cfu/100 ml *enterococci* in estuarine waters. In TMDL development, the in-stream *E. coli* and *enterococci* targets were a geometric mean not exceeding 126-cfu/100 ml and a single sample maximum of 235-cfu/100 ml for *E. coli*, or a geometric mean not exceeding 35-cfu/100 ml and a single sample maximum of 104-cfu/100 ml for *enterococci*. Translator equations developed by VADEQ were used to convert fecal coliform values to *E. coli* and *enterococci* values.

Water Quality Modeling

The U.S. Geological Survey (USGS) Hydrologic Simulation Program - Fortran (HSPF) water quality model was selected as the modeling framework to simulate existing conditions and perform TMDL allocations in the Virginia Beach Coastal Study Area. Due to the complex landuses and tributary networks of the tidal areas, HSPF is well suited for providing runoff inputs to a suitable tidal model, provided that the tidal model possesses the ability to receive temporally and spatially varying inputs from HSPF. CE-QUAL-W2 (Army Corps of Engineers, 2003) meets the requirements of modeling this system, including time varying point and non-point sources, wind, tides, a first order decay-based general quality constituent component (including a settling routine for fecal coliform if desired) and continuous simulation. The model’s main limitation is its lateral averaging, which is why it is preferred for use with narrow bodies of water such as those in the Virginia Beach Coastal TMDL Study Area. In establishing the existing and allocation conditions, seasonal variations in hydrology, climatic conditions, and watershed activities were explicitly accounted for in the model. Due to the requirements of HSPF the Virginia Beach Coastal Study Area was subdivided into 44 subwatersheds for the hydrology analysis. The flow period used for hydrologic calibration depended on the data available. A calibration period of January 1998 through June 1998 was used for the hydrology. The water quality calibration period was conducted using monitored data collected at VADEQ monitoring stations between February 1998 and December 1998.

Existing Conditions

Wildlife populations and ranges; rates of failure, locations, and number of septic systems; domestic pet populations; numbers of cattle and other livestock; and information on livestock and manure management practices for the Virginia Beach Coastal Study Area watershed were used to calculate fecal coliform loads from land-based nonpoint sources in the watershed. The estimated fecal coliform production and accumulation rates due to these sources were calculated for the watershed and incorporated into the model. To accommodate the structure of the model, calculation of the fecal coliform accumulation and source contributions on a monthly basis accounted for seasonal variation in watershed activities such as wildlife feeding patterns and land application of manure. Also, represented in the model were direct nonpoint sources of uncontrolled discharges, and direct deposition by wildlife.

Contributions from all of these sources were updated to 2004 conditions to establish existing conditions for the watershed. All runs were made using a representative precipitation record. Under existing conditions (2004), the HSPF model provided a comparable match to the VADEQ monitoring data, with output from the model indicating violations of both the instantaneous and geometric mean standards throughout the watershed.

Load Allocation Scenarios

The next step in the TMDL process was to determine how to proceed from existing watershed conditions in order to reduce the various source loads to levels that would result in attainment of the water quality standards. Because USEPA requires a zero percent violation load allocation in TMDLs, modeling was conducted for a target value of 0% exceedance of the 126-cfu/100 ml geometric mean standard and 0% exceedance of the sample maximum *E. coli* standard of-235 cfu/100 ml and of the 35 cfu/100ml and 104 cfu/100ml *enterococci* standard. Scenarios were evaluated to predict the effects of different combinations of source reductions on final in-stream water quality. Modeling of these scenarios provided predictions of whether the reductions would achieve the target of 0% exceedance. The reductions in percentages in loading from existing conditions are given in Tables ES1 through ES5. Scenario three would generally be adopted as the targets for a Stage I implementation goals. The Stage I water quality goal was to reduce the number of violations of the instantaneous standard in the impaired segments to less than 10%. The last scenario, either six or seven, shows the reductions necessary to achieve zero percent violation compliance.

Table ES.1 Allocation scenarios for bacterial concentration with current loading estimates in London Bridge Creek & Canal #2.

Scenario Number	Percent Reduction in Loading from Existing Conditions					Percent Violations	
	Direct Wildlife	NPS Forest / Wetland	NPS Pasture / Livestock Access / Crops	Straight Pipe / Sewer Overflow	NPS Res. / Urban	GM > 35 cfu/100ml	Single Sample > 104 cfu / 100ml
1	0	0	0	0	0	100	19.38
2	0	0	100	100	100	0.00	0.00
3[1]	0	0	50	100	50	100	9.06
4	0	0	80	100	80	8.33	0.94
5	0	0	85	100	85	8.33	0.31
6[2]	0	0	88	100	88	0.00	0.00

[1]Stage I implementation scenario.
[2]Final 0% TMDL allocation.

Table ES.2 Allocation scenarios for bacterial concentration with current loading estimates in Milldam Creek.

Scenario Number	Percent Reduction in Loading from Existing Conditions					Percent Violations	
	Direct Wildlife	NPS Forest / Wetland	NPS Pasture / Livestock Access / Crops	Straight Pipe / Sewer Overflow	NPS Res. / Urban	GM > 126 cfu/100ml	Single Sample > 235 cfu / 100ml
1	0	0	0	0	0	58.33	7.19
2	0	0	100	100	100	0.00	4.38
3[1]	0	0	50	100	50	8.33	5.31
4	0	0	90	90	90	0.00	3.75
5	0	65	99	100	99	0.00	1.25
6	0	83	99	100	99	0.00	0.31
7[2]	0	91	99	100	99	0.00	0.00

[1]Stage I implementation scenario.
[2]Final 0% TMDL allocation.

Table ES.3 Allocation scenarios for bacterial concentration with current loading estimates in Nawney Creek.

Scenario Number	Percent Reduction in Loading from Existing Conditions					Percent Violations	
	Direct Wildlife	NPS Forest / Wetland	NPS Pasture / Livestock Access / Crops	Straight Pipe / Sewer Overflow	NPS Res. / Urban	GM > 35 cfu/100ml	Single Sample > 104 cfu / 100ml
1	0	0	0	0	0	100.00	6.88
2	0	0	100	100	100	0.00	0.00
3[1]	0	0	15	100	15	33.00	5.00
4	0	0	50	100	50	16.66	3.44
5	0	0	80	100	80	0.00	1.31
6[2]	0	0	85	100	85	0.00	0.00

[1]Stage I implementation scenario.
[2]Final 0% TMDL allocation.

Table ES.4 Allocation scenarios for bacterial concentration with current loading estimates in West Neck Creek (Middle).

Scenario Number	Percent Reduction in Loading from Existing Conditions					Percent Violations	
	Direct Wildlife	NPS Forest / Wetland	NPS Pasture / Livestock Access / Crops	Straight Pipe / Sewer Overflow	NPS Res. / Urban	GM > 126 cfu/100ml	Single Sample > 235 cfu / 100ml
1	0	0	0	0	0	25.00	15.63
2	0	0	100	100	100	0.00	0.00
3[1]	0	0	50	100	50	0.00	4.69
4	0	0	80	100	80	0.00	0.31
5	0	0	82	100	82	0.00	0.31
6[2]	0	0	84	100	84	0.00	0.00

[1]Stage I implementation scenario.
[2]Final 0% TMDL allocation.

Table ES.5 Allocation scenarios for bacterial concentration with current loading estimates in West Neck Creek (Upper).

Scenario Number	Percent Reduction in Loading from Existing Conditions					Percent Violations	
	Direct Wildlife	NPS Forest / Wetland	NPS Pasture / Livestock Access / Crops	Straight Pipe / Sewer Overflow	NPS Res. / Urban	GM > 35 cfu/100ml	Single Sample > 104 cfu / 100ml
1	0	0	0	0	0	100.00	15.94
2	0	0	100	100	100	0.00	0.00
3[1]	0	0	50	100	50	83.33	5.00
4	0	0	80	100	80	8.33	0.31
5	0	0	83	100	83	8.33	0.31
6[2]	0	0	85	100	85	0.00	0.00

[1]Stage I implementation scenario.
[2]Final 0% TMDL allocation.

Implementation

The goal of the TMDL program is to establish a three-step path that will lead to attainment of water quality standards. The first step in the process is to develop TMDLs that will result in meeting water quality standards. This report represents the culmination of that effort for the bacteria impairments on the Virginia Beach Coastal Study Area. The second step is to develop a TMDL implementation plan (IP). The final step is to implement the TMDL IP, and to monitor stream water quality to determine if water quality standards are being attained.

Once EPA has approved a TMDL, measures must be taken to reduce pollution levels in the stream. These measures, which can include the use of better treatment technology and the installation of best management practices (BMPs), are implemented in an iterative process that is described along with specific BMPs in the IP. The process for developing an implementation plan has been described in the recent *Guidance Manual for Total Maximum Daily Load Implementation Plans,* published in July 2003 and available upon request from the VADEQ and VADCR TMDL project staff or at http://www.deq.state.va.us/tmdl/implans/ipguide.pdf. With successful completion of implementation plans, Virginia will be well on the way to restoring impaired waters and enhancing the value of this important resource. Additionally, development of an approved implementation plan will improve a locality's chances for obtaining financial and technical assistance during implementation.

In general, Virginia intends that the required reductions be implemented in an iterative process that first addresses those sources with the largest impact on water quality. For example, in agricultural areas of the watershed, the most promising management practice to control bacteria and minimize stream bank erosion is livestock exclusion from streams. This has been shown to be very effective in lowering bacteria concentrations in streams, both by reducing the cattle deposits themselves and by providing additional riparian buffers. Additionally, in both urban and rural areas, reducing the human bacteria loading from failing septic systems should be a primary implementation focus because of its health implications. This component could be implemented through education on septic tank pump-outs as well as a septic system repair/replacement program and the use of alternative waste treatment systems.

Watershed stakeholders will have the opportunity to participate in the development of the TMDL Implementation Plan. While specific goals for BMP implementation will be established as part of the implementation plan development, the Stage I scenarios are targeted at controllable, anthropogenic bacteria.

Public Participation

During development of the TMDL for the Virginia Beach Coastal Study Area watershed, public involvement was encouraged through 2 meetings.

Table ES.6 Public Meetings for the Virginia Beach Coastal Study Area

Impairment	Date	Location
1st Public meeting	10/20/2004	DEQ Tidewater Regional Office Virginia Beach, VA
Final Public meeting	1/20/2005	Advanced Technology Center Tidewater Community College – Virginia Beach Campus Virginia Beach, VA

1. INTRODUCTION

1.1 Background

The need for TMDLs to be conducted in the Virginia Beach Coastal Area is based on provisions of the Clean Water Act. The document, *Guidance for Water Quality-Based Decisions: The TMDL Process* (EPA, 1999), states:

> *According to Section 303(d) of the Clean Water Act and EPA water quality planning and management regulations, States are required to identify waters that do not meet or are not expected to meet water quality standards even after technology-based or other required controls are in place. The waterbodies are considered water quality-limited and require TMDLs.*
>
> *…A TMDL is a tool for implementing State water quality standards, and is based on the relationship between pollution sources and in-stream water quality conditions. The TMDL establishes the allowable loadings or other quantifiable parameters for a waterbody and thereby provides the basis for States to establish water quality-based controls. These controls should provide the pollution reduction necessary for a waterbody to meet water quality standards.*

The Albemarle and Lynnhaven-Poquoson watersheds (contained in USGS Hydrologic Unit Codes 03010205 and 02080108, respectively) (Figure 1.1) drain to the Currituck Sound and Chesapeake Bay, respectively. The Albemarle watershed contains impaired segments of Nawney Creek, which drains to Back Bay, and Milldam Creek and West Neck Creek (middle), which both drain to the North Landing River. The Albemarle watershed includes portions of Virginia Beach City and Chesapeake City; the upper portion of West Neck Creek has recently (2004) been moved from the Albemarle watershed to the Lynnhaven-Poquoson watershed, as West Neck Creek drains to London Bridge Creek. The London Bridge Creek and Canal #2 impairment is in the Lynnhaven-Poquoson watershed, and drains to the Lynnhaven Bay. As the Upper West Neck Creek and London Bridge Creek and Canal #2 impaired segments are linked by tidal processes to the impaired segments of the Albemarle watershed, they are included in this report (Figure 1.2). The Virginia Department of Environmental Quality (VADEQ) has identified all of these segments as impaired with regard to fecal coliform.

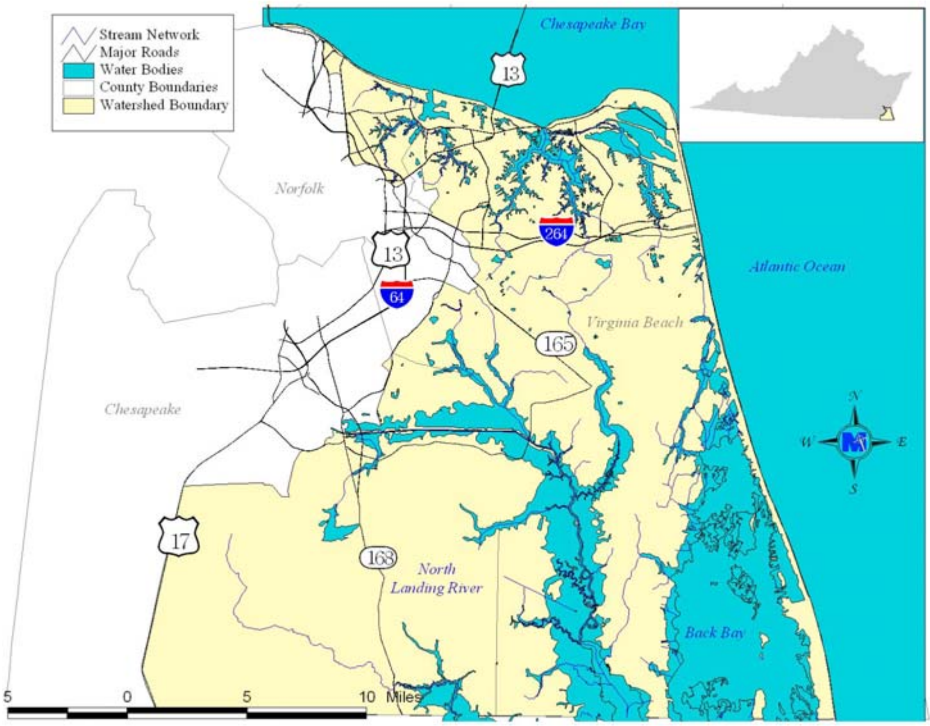


Figure 1.1 Location of the Albemarle and Lynnhaven-Poquoson watersheds.

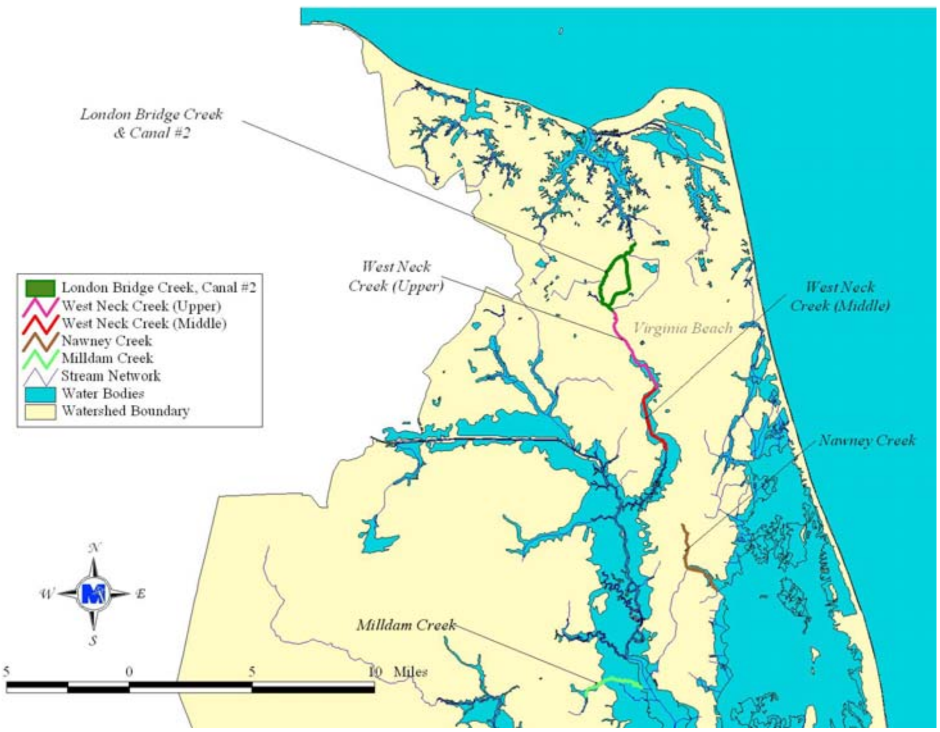


Figure 1.2 Impaired stream segments in the Albemarle and Lynnhaven-Poquoson watersheds.

Table 1.1 lists, for each impairment, the VADEQ water quality monitoring station used for impaired waters assessment, initial year the segment was listed in the Section 303(d) list, current miles affected in the 2004 listing, fecal coliform violation rates in the *Virginia 2002 Section 303(d) Report on Impaired Waters* and the *Virginia 2004 Section 305(b)/303(d) Water Quality Integrated Report*, and location of listing.

Table 1.1 Fecal coliform impairments on *Virginia 2004 Section 305(b)/303(d) Water Quality Integrated Report* within the Virginia Beach Coastal Area.

Stream Name, HUP	Listing Station ID	Initial Listing	Miles Affected	2002 303(d) List FC Violation Rate	2004 303(d) List FC Violation Rate	Location
London Bridge Creek & Canal #2, C08	7LOB003.70 7LOB001.79 7XBO001.30	1996	0.11+	19/32 19/59 8/36	27/31 23/50 22/50	Segment begins at Ships Corner ends at confluence of Thurston Branch. Includes all of Canal #2
Milldam Creek, K41	5BMLD001.92	2002	3.29	7/58	9/50	From headwaters downstream to confluence with North Landing River
Nawney Creek (Upper), K42	5BNWN001.84	1996	0.03+	5/52	12/45	Segment extends 0.8 mile up and 0.6 mile downstream of Nawney Creek Road bridge
Nawney Creek (Lower), K42	5BNWN000.00	1996	0.06+	7/51	8/44	Segment begins 0.6 miles downstream of Nawney Creek Road bridge and ends at confluence with Back Bay
West Neck Creek (Middle), K41	5BWNC003.65	1998	3.1	1/51	7/44	From south side of Princess Anne Road crossing to widening of creek approximately 0.55 miles downstream of Indian River Road crossing
West Neck Creek (Upper), C08	5BWNC010.02	1998	0.03+	18/59	19/47	From Princess Anne Road crossing to junction with London Bridge Creek

+ Units are square miles.

The London Bridge and Canal #2 impairment, as well as the Nawney Creek impairments were initially placed on the Virginia 1996 Section 303(d) TMDL Priority List and Report based on monitoring performed. Additional stream segments within the Virginia Beach Coastal Area were successively placed on the 1998 303(d) Total Maximum Daily Load Priority List and Report, and the 2002 303(d) Report on Impaired Waters (Table 1.1). All segments remained on the 2004 305(b)/303(d) Water Quality Integrated Report. Elevated levels of fecal coliform bacteria recorded at VADEQ ambient water quality monitoring stations showed that Virginia Beach Coastal Area stream segments do not support the primary contact recreation use.

VADEQ's 2004 305(b)/303(d) Water Quality Integrated Report lists two impaired segments of Nawney Creek for fecal coliform (Upper and Lower). For the purposes of this report, the Upper and Lower segments shall be referred to together as Nawney Creek.

2. TMDL ENDPOINT AND WATER QUALITY ASSESSMENT

2.1 Applicable Water Quality Standards

According to 9 VAC 25-260-5 of Virginia's State Water Control Board *Water Quality Standards*, the term "water quality standards" means "…provisions of state or federal law which consist of a designated use or uses for the waters of the Commonwealth and water quality criteria for such waters based upon such uses. Water quality standards are to protect the public health or welfare, enhance the quality of water and serve the purposes of the State Water Control Law and the federal Clean Water Act."

As stated in Virginia state law 9 VAC 25-260-10 (Designation of uses),

> *A. All state waters, including wetlands, are designated for the following uses: recreational uses, e.g., swimming and boating; the propagation and growth of a balanced, indigenous population of aquatic life, including game fish, which might reasonably be expected to inhabit them; wildlife; and the production of edible and marketable natural resources, e.g., fish and shellfish.*
>
> ♦
>
> *D. At a minimum, uses are deemed attainable if they can be achieved by the imposition of effluent limits required under §§301(b) and 306 of the Clean Water Act and cost-effective and reasonable best management practices for nonpoint source control.*

Section 9 VAC 25-260-170 is the applicable water quality criteria for fecal coliform impairments in the Albemarle and Lynnhaven-Poquoson watersheds.

Prior to 2002, Virginia Water Quality Standards specified the following criteria for a non-shellfish supporting waterbody to be in compliance with Virginia's fecal standard for contact recreational use:

> *A. General requirements. In all surface waters, except shellfish waters and certain waters addressed in subsection B of this section, the fecal coliform bacteria shall not exceed a geometric mean of 200 fecal coliform bacteria per 100 ml of water for two or more samples over a 30-day period, or a fecal coliform bacteria level of 1,000 per 100 ml at any time.*

If the waterbody had an exceedance rate > 10.5% and had at least 2 exceedances, the waterbody was classified as impaired and the development and implementation of a TMDL was indicated in order to bring the waterbody into compliance with the water quality criterion. Based on the sampling frequency, only one criterion was applied to a particular datum or data set. If the sampling frequency was one sample or less per 30 days, the instantaneous criterion was applied; for a higher sampling frequency, the geometric criterion was applied. This was the criterion used for listing the impairments included in this study. Sufficient fecal coliform bacteria standard violations were recorded at VADEQ water quality monitoring stations to indicate that the recreational use designations are not being supported.

The EPA has since recommended that all states adopt an *E coli* or *enterococci* standard for fresh water and *enterococci* criteria for marine waters by 2003. EPA is pursuing the states' adoption of these standards because there is a stronger correlation between the concentration of these organisms (*E. coli* and *enterococci*) and the incidence of gastrointestinal illness than with fecal coliform. *E. coli* and *enterococci* are both bacteriological organisms that can be found in the intestinal tract of warm-blooded animals. Like fecal coliform bacteria, these organisms indicate the presence of fecal contamination. The adoption of the *E. coli* and *enterococci* standard went into effect January 15, 2003 in Virginia.

The new criteria, used in developing the bacteria TMDL in this study, is outlined in 9 VAC 25-260-170 and reads as follows

> *A. In surface waters, except shellfish waters and certain waters identified in subsection B of this section, the following criteria shall apply to protect primary contact recreational uses:*
>
> *1. Fecal coliform bacteria shall not exceed a geometric mean of 200 fecal coliform bacteria per 100 ml of water for two or more samples over a calendar month nor shall more than 10% of the total samples taken during any calendar month exceed 400 fecal coliform bacteria per 100 ml of water. This criterion shall not apply for a sampling station after the bacterial indicators described in subdivision 2 of this subsection have a minimum of 12 data points or after June 30, 2008, whichever comes first.*
>
> *2. E. coli and enterococci bacteria per 100 ml of water shall not exceed the following:*

	Geometric Mean[1]	Single Sample Maximum[2]

Freshwater[3]		
E. coli	*126*	*235*
Saltwater and Transition Zone[3]		
Enterococci	*35*	*104*

[1] For two or more samples taken during any calendar month.
[2] No single sample maximum for *enterococci* and *E. coli* shall exceed a 75% upper one-sided confidence limit based on a site-specific log standard deviation. If site data are insufficient to establish a site-specific log standard deviation, then 0.4 shall be used as the log standard deviation in freshwater and 0.7 shall be as the log standard deviation in saltwater and transition zone. Values shown are based on a log standard deviation of 0.4 in freshwater and 0.7 in saltwater.
[3] See 9 VAC 25-260-140 C for freshwater and transition zone delineation.

2.2 Selection of a TMDL Endpoint.

The first step in developing a TMDL is the establishment of in-stream numeric endpoints, which are used to evaluate the attainment of acceptable water quality. In-stream numeric endpoints, therefore, represent the water quality goals that are to be achieved by implementing the load reductions specified in the TMDL. For the Virginia Beach Coastal Area TMDLs, the applicable endpoints and associated target values can be determined directly from the Virginia water quality regulations (Table 2.1). In order to remove a waterbody from a state's list of impaired waters, the Clean Water Act requires compliance with that state's water quality standard. Since modeling provided simulated output of *E. coli* concentrations at 1-hour intervals, assessment of TMDLs was made using both the geometric mean standard of 126 cfu/100 ml and the instantaneous standard of 235 cfu/100 ml. Therefore, the in-stream *E. coli* targets for these TMDLs were a monthly geometric mean not exceeding 126 cfu/100 ml and a single sample not exceeding 235 cfu/100 ml.

Table 2.1 Listing Criteria and TMDL Endpoints for the impairments in the Virginia Beach Coastal Area.

Stream Name	Listing Criterion	TMDL Endpoint
London Bridge & Canal #2	Fecal coliform, *enterococci*	*enterococci*
Milldam Creek	Fecal coliform	*E. coli*
Nawney Creek	Fecal coliform, *enterococci*	*enterococci*
West Neck Creek (middle)	Fecal coliform	*E. coli*
West Neck Creek (upper)	Fecal coliform, *enterococci*	*enterococci*

2.3 Selection of a TMDL Critical Condition.

EPA regulations at 40 CFR 130.7 (c)(1) require TMDLs to take into account critical conditions for stream flow, loading, and water quality parameters. The intent of this requirement is to ensure that the water quality of the Virginia Beach Coastal Area is protected during times when it is most vulnerable.

Critical conditions are important because they describe the factors that combine to cause a violation of water quality standards and will help in identifying the actions that may have to be undertaken in order to meet water quality standards. Fecal bacteria sources within the Virginia Beach Coastal Area are attributed to both point and non-point sources. Critical conditions for waters impacted by land-based non-point sources generally occur during periods of wet weather and high surface runoff. In contrast, critical conditions for point source-dominated systems generally occur during low flow and low dilution conditions. Point sources, in this context also, include non-point sources that are not precipitation driven (*e.g.,* fecal deposition to stream).

A graphical analysis of fecal coliform concentrations and flow duration interval showed that there was no obvious critical flow level (Figures 2.1 through 2.8). That is, the analysis showed no obvious dominance of either non-point sources or point sources. High concentrations were recorded in all flow regimes at monitoring stations where data were collected during all flow regimes. Based on this analysis, a time period for calibration and validation of the model was chosen based on the overall distribution of wet and dry seasons (Section 4.5) in order to capture the a wide range of hydrologic circumstances for all impaired streams in this study area. The resulting periods for calibration and validation for each impaired stream are presented in Chapter 4.

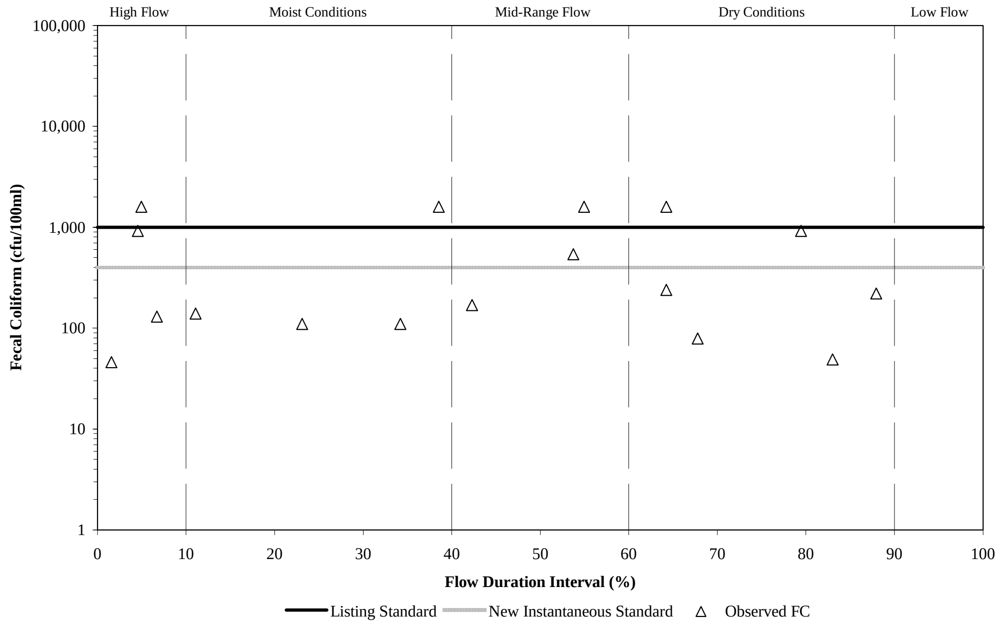


Figure 2.1 Relationship between fecal coliform concentrations (VADEQ Station 5BWNC010.02) and discharge (USGS Gaging Station #02043200) in the West Neck Creek (Upper) impairment.

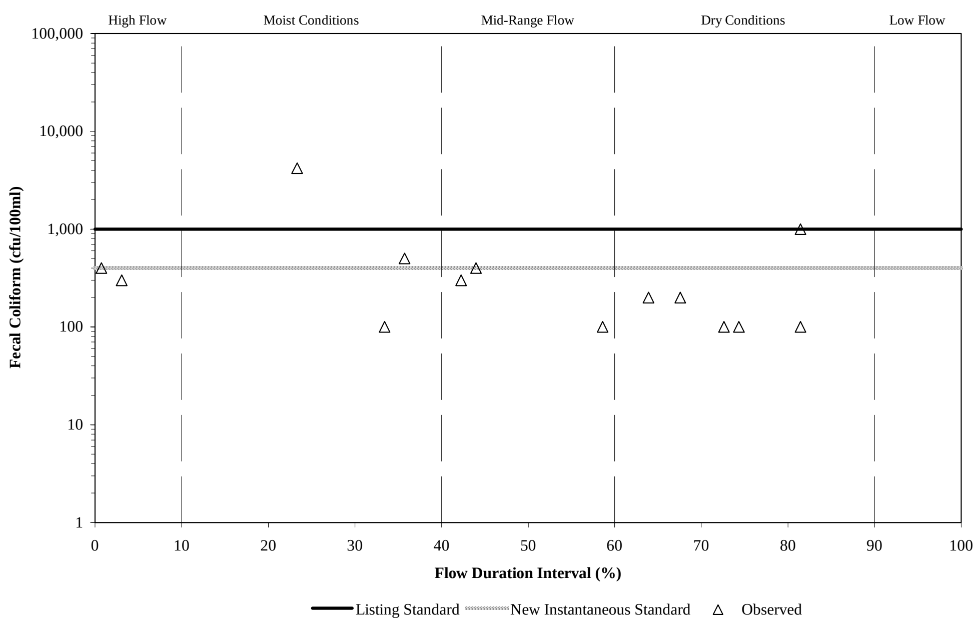


Figure 2.2 Relationship between fecal coliform concentrations (VADEQ Station 5WNC003.65) and discharge (USGS Gaging Stations #02043200 and #02043190) in the West Neck Creek (Middle) impairment.

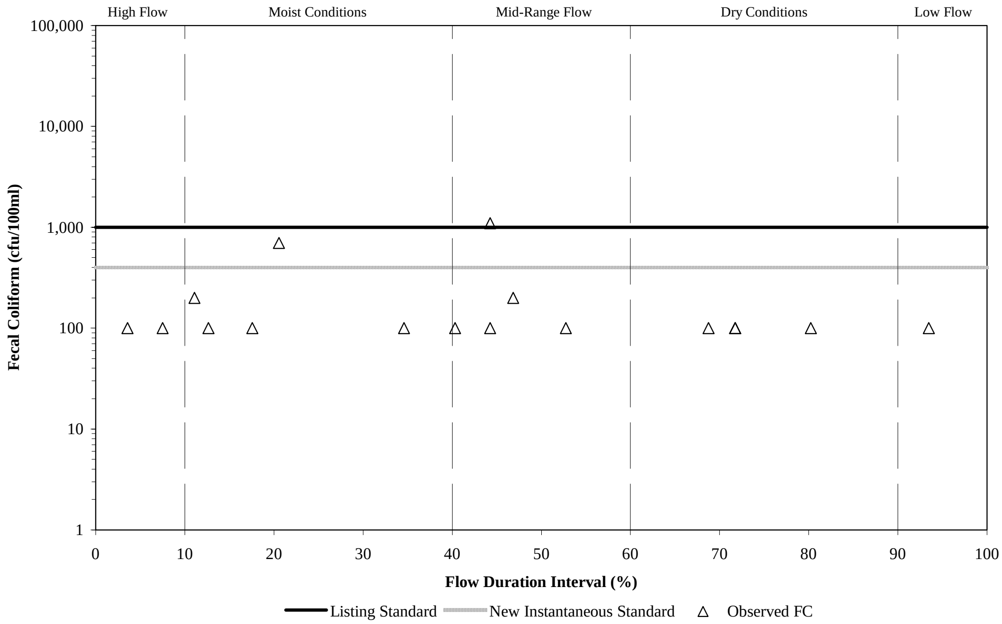


Figure 2.3 Relationship between fecal coliform concentrations (VADEQ Station 5BMLD001.92) and discharge (USGS Gaging Station #02043200) in the Milldam Creek impairment.

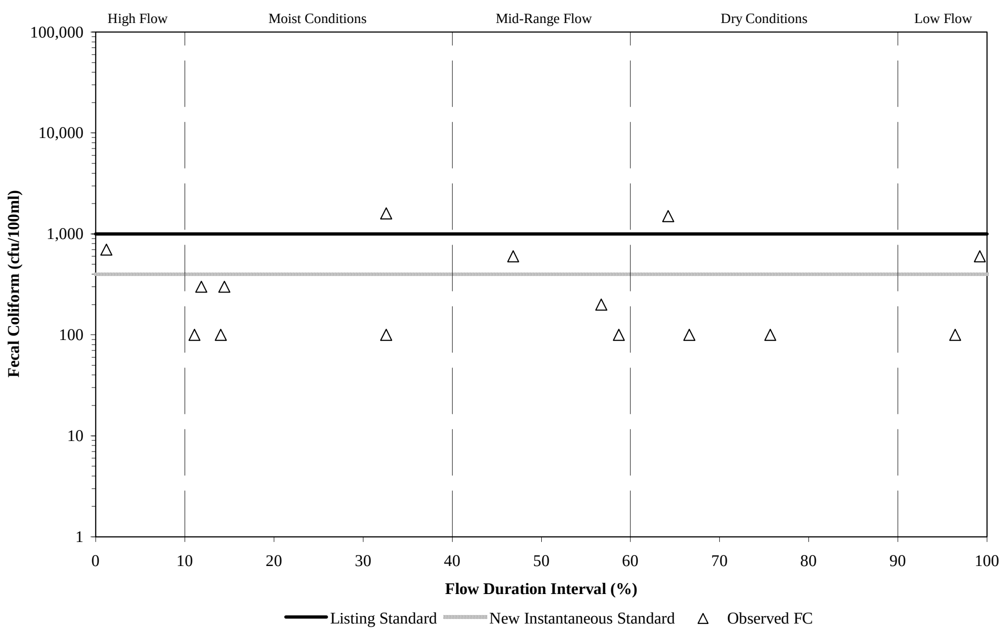


Figure 2.4 Relationship between fecal coliform concentrations (VADEQ Station 5BNWN001.84) and discharge (USGS Gaging Station #02043200) in the Nawney Creek (upper) impairment.

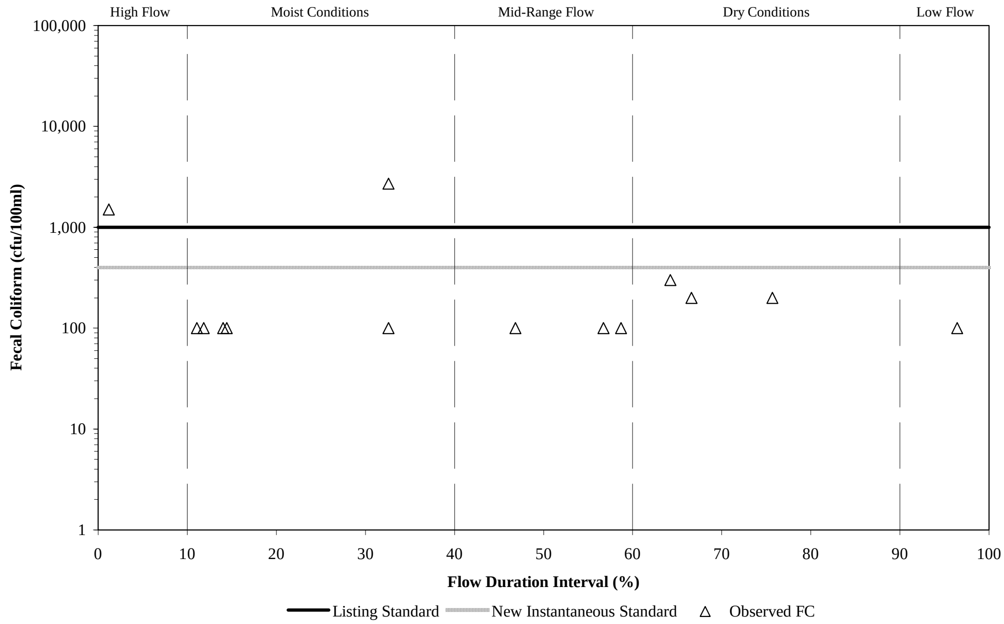


Figure 2.5 Relationship between fecal coliform concentrations (VADEQ Station 5BNWN000.00) and discharge (USGS Gaging Station #02043200) in the Nawney Creek (lower) impairment.

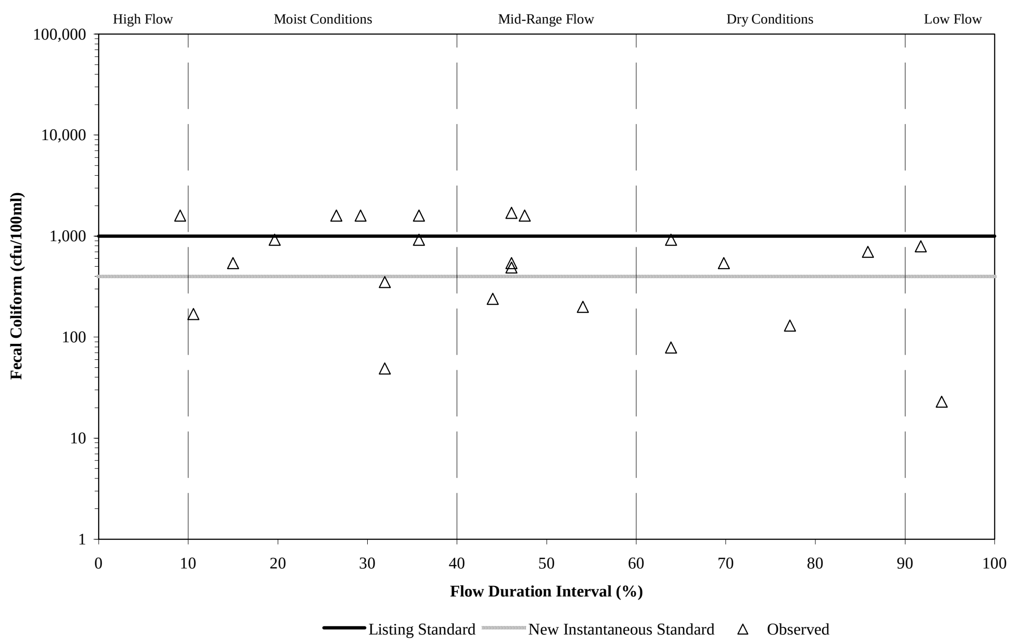


Figure 2.6 Relationship between fecal coliform concentrations (VADEQ Station 7-LOB001.79) and discharge (USGS Gaging Stations #02043200 and #02043190) in the London Bridge Creek impairment.

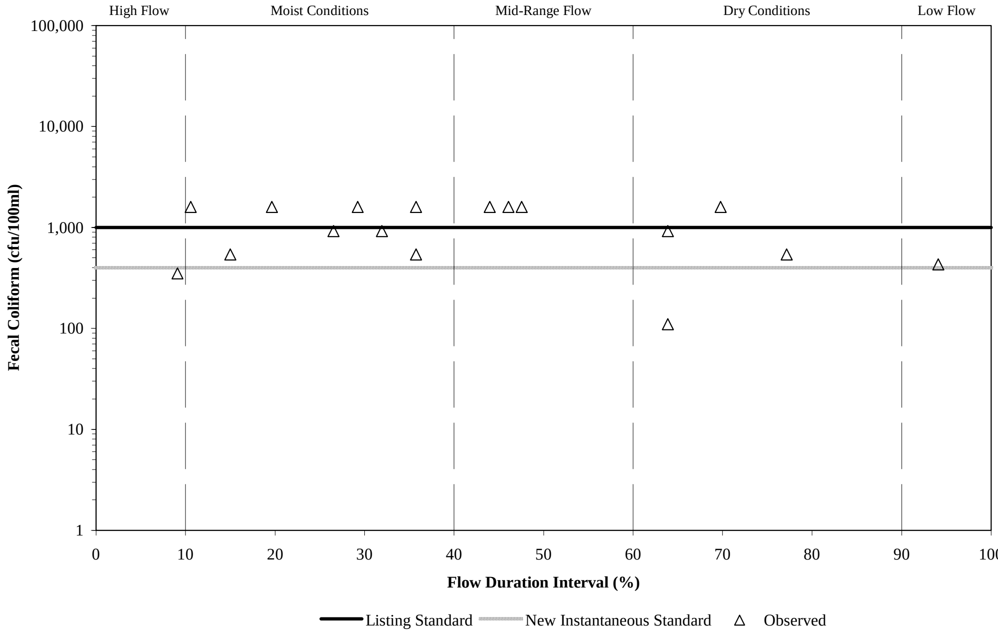


Figure 2.7 Relationship between fecal coliform concentrations (VADEQ Station 7-LOB003.70) and discharge (USGS Gaging Stations #02043200 and #02043190) in the London Bridge Creek impairment.

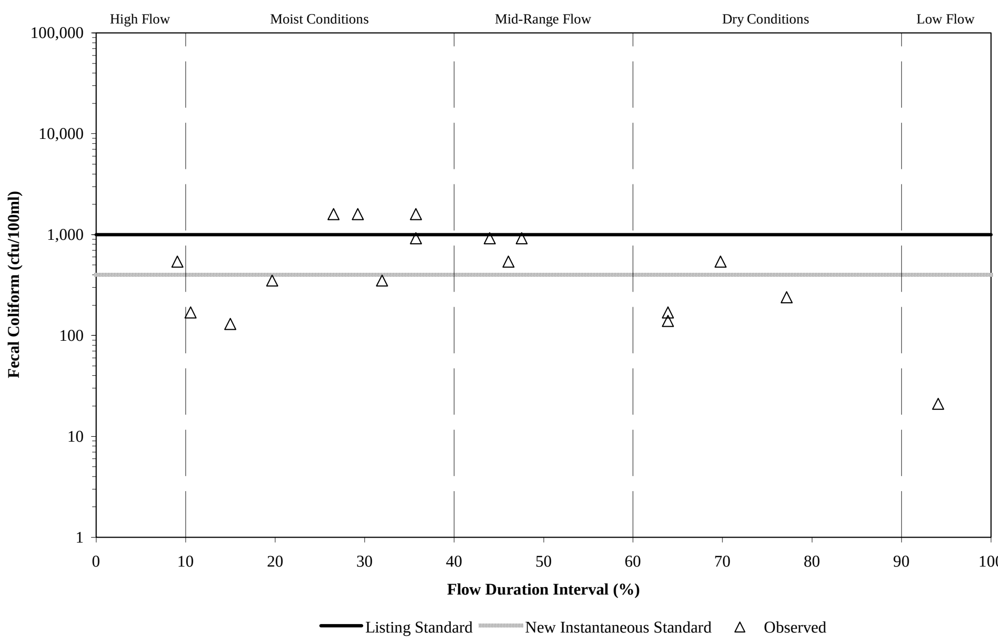


Figure 2.8 Relationship between fecal coliform concentrations (VADEQ Station 7-XBO001.30) and discharge (USGS Gaging Stations #02043200 and #02043190) in the Canal # 2 impairment.

2.4 Discussion of In-stream Water Quality

This section provides an inventory and analysis of available observed in-stream fecal coliform monitoring data throughout the Virginia Beach Coastal Area watersheds. An examination of data from water quality stations used in the 303(d) assessment was performed and data collected during TMDL development were analyzed. Sources of data and pertinent results are discussed.

2.4.1 Inventory of Water Quality Monitoring Data

The primary sources of available water quality information are:

- Bacteria enumerations from 9 VADEQ in-stream monitoring stations used for TMDL assessment; and
- Bacteria enumerations and bacterial source tracking (BST) from 3 VADEQ in-stream monitoring stations analyzed during TMDL development.

2.4.1.1 Water Quality Monitoring for TMDL Assessment

Data from in-stream fecal coliform samples, collected by VADEQ, were analyzed from February 1968 through March 2004 (Figure 2. 9) and are included in the analysis. Samples were taken for the express purpose of determining compliance with the state instantaneous standard limiting concentrations to less than 400 cfu/100 ml. Therefore, as a matter of economy, samples showing fecal coliform concentrations below 100 cfu/100 ml or in excess of a specified cap (*e.g.*, 8,000 or 16,000 cfu/100 ml, depending on the laboratory procedures employed for the sample) were not further analyzed to determine the precise concentration of fecal coliform bacteria. The result is that reported concentrations of 100 cfu/100 ml most likely represent concentrations below 100 cfu/100 ml, and reported concentrations of 8,000 or 16,000 cfu/100 ml most likely represent concentrations in excess of these values. Table 2.2 summarizes the fecal coliform samples collected at the in-stream monitoring stations used for TMDL assessment.

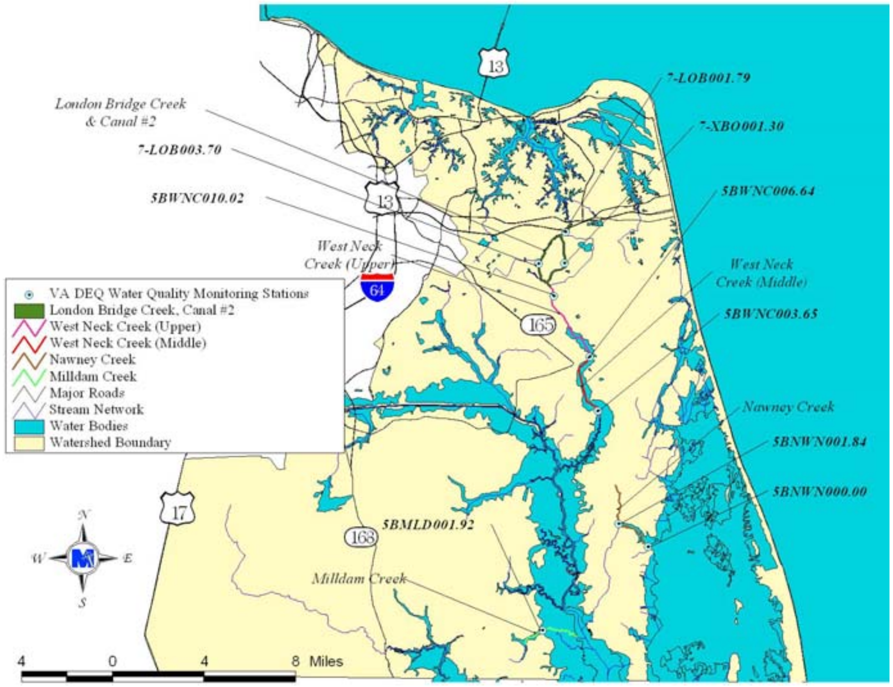


Figure 2.9 Location of VADEQ water quality monitoring stations used for TMDL assessment in the Albemarle and Lynnhaven – Poquoson River watersheds.

Table 2.2 Summary of fecal coliform, *E. coli* and *enterococci* (cfu/100 ml) sampling conducted by VADEQ for period February 1968 through May 2004.

Stream Name	Station Id	Sampled Dates	Count	Parameter Name	Minimum	Maximum	Mean	Median
London Bridge Creek	7LOB001.79	1/90-3/04	151	Fecal coliform	11	16,000	1,028	540
		7/02-3/04	11	*E. coli*	20	800	275	170
		7/02-8/04	13	*enterococci*	40	2,000	425	290
London Bridge Creek	7LOB003.70	12/97-8/00	32	Fecal coliform	95	1,600	1,167	1,600
Canal #2	7XBO001.30	12/97-3/04	58	Fecal coliform	17	1,700	573	350
		7/02-3/04	10	*E. coli*	10	800	199	145
Milldam Creek	5BMLD001.92	9/95-3/04	83	Fecal coliform	49	8,000	406	100
		7/02-3/04	10	*E. coli*	10	620	184	75
Nawney Creek	5BNWN000.00	6/93-3/04	100	Fecal coliform	25	4,700	589	200
		7/02-3/04	10	*E. coli*	10	750	159	60
		7/02-9/04	14	*enterococci*	10	2,000	278	55
Nawney Creek	5BNWN001.84	6/93-3/04	100	Fecal coliform	25	2,900	528	210
		7/02-3/04	9	*E. coli*	10	420	139	90
West Neck Creek (Middle)	5BWNC003.65	6/91-5/04	103	Fecal coliform	25	4,200	307	100
		7/02-5/04	11	*E. coli*	10	800	134	50

Table 2.2 Summary of fecal coliform, *E. coli* and *enterococci* (cfu/100 ml) sampling conducted by VADEQ for period February 1968 through May 2004 (cont.).

Stream Name	Station Id	Sampled Dates	Count	Parameter Name	Minimum	Maximum	Mean	Median
West Neck Creek (Middle)	5BWNC006.64	6/72-5/79	70	Fecal coliform	19	8,000	953	105
West Neck Creek (Upper)	5BWNC010.02	9/95-3/04	86	Fecal coliform	22	2,000	715	350
		7/02-3/04	11	*E. coli*	10	800	264	200
		7/02-8/04	13	*enterococci*	10	2,000	370	280

2.4.1.2 Water Quality Monitoring Conducted During TMDL Development

Ambient water quality monitoring was performed from August 2003 through July 2004. Specifically, water quality samples were taken at 8 sites throughout the Virginia Beach Coastal Area. Samples were analyzed for fecal coliform, *E. coli* and *enterococci* concentrations, based upon the nature of the impairment. Three of these sites were also analyzed for bacteria source (*i.e.*, human, livestock, pet, wildlife) by the Environmental Diagnostics Laboratory (EDL) at MapTech, Inc. (Figure 2.10). Tables 2.3 through 2.5 summarize the fecal coliform, *E. coli*, and *enterococci* concentration data, respectively, at the ambient stations. BST results are presented and discussed in greater detail in Section 2.4.2.1.

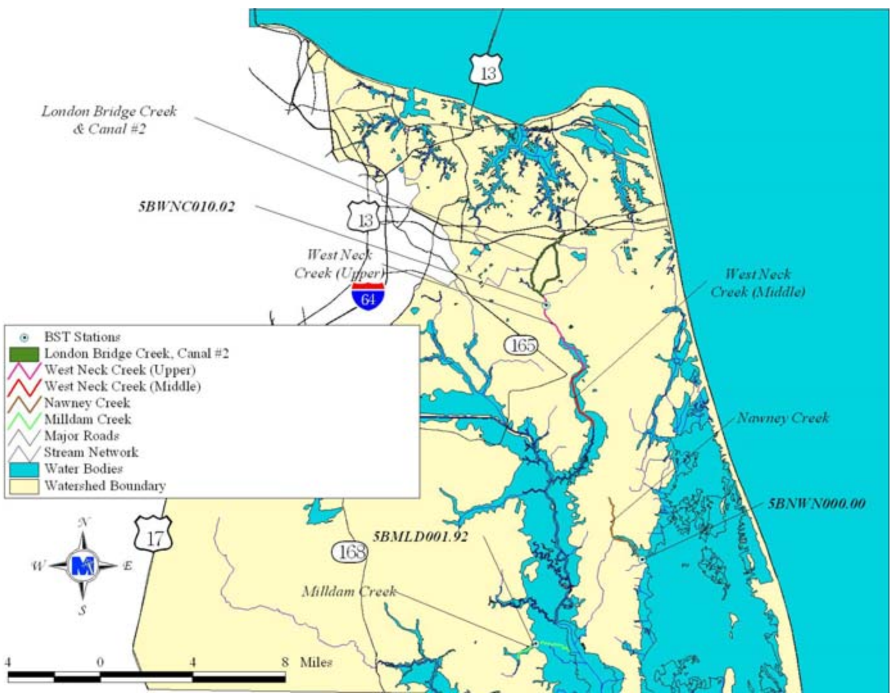


Figure 2.10 Location of BST and DEQ water quality monitoring stations in the Albemarle and Lynnhaven-Poquoson River watersheds.

Table 2.3 Summary of fecal coliform (cfu/100 ml) sampling conducted by VADEQ during TMDL development.

Impairment	Station	Count (#)	Minimum (cfu/100ml)	Maximum (cfu/100ml)	Mean (cfu/100ml)	Median (cfu/100ml)	Violations[1] (%)
London Bridge Creek	7LOB001.79	11	18	2,000	468	330	27
Canal #2	7XBO001.30	10	18	2,000	420	265	40
Milldam Creek	5BMLD001.92	12	1	2,000	318	110	17
Nawney Creek	5BNWN000.00	11	20	6,500	706	70	9
	5BNWN001.84	10	25	2,000	602	175	30
West Neck Creek	5BWNC001.73	11	25	280	104	75	0
	5BWNC003.65	11	25	2,000	595	50	27
	5BWNC010.02	12	10	18,000	2,653	225	33

[1]Violations based on new fecal coliform instantaneous standard (*i.e.*, 400 cfu/100ml)

Table 2.4 Summary of *E. coli* (cfu/100 ml) sampling conducted by VADEQ during TMDL development.

Impairment	Station	Count (#)	Minimum (cfu/100ml)	Maximum (cfu/100ml)	Mean (cfu/100ml)	Median (cfu/100ml)	Violations[1] (%)
London Bridge Creek	7LOB001.79	8	20	800	224	135	38
Canal #2	7XBO001.30	7	10	290	129	110	14
Milldam Creek	5BMLD001.92	12	20	148	55	41	0
Nawney Creek	5BNWN000.00	11	28	260	76	40	9
	5BNWN001.84	10	10	420	142	125	20
West Neck Creek	5BWNC001.73	14	10	450	87	25	14
	5BWNC003.65	11	10	800	134	50	9
	5BWNC010.02	12	38	7,200	1,347	120	33

[1]Violations based on *E. coli* instantaneous standard (*i.e.*, 235 cfu/100ml)

Table 2.5 Summary of *enterococci* (cfu/100 ml) sampling conducted by VADEQ during TMDL development.

Impairment	Station ID	Count	Minimum	Maximum	Mean	Median	% Violations
London Bridge	7LOB001.79	10	40	2,000	424	280	70
Nawney Creek	5BNWN000.00	11	10	2,000	276	60	36
West Neck Creek (Upper)	5BWNC010.02	10	10	2,000	401	285	70

[1]Violations based on *enterococci* instantaneous standard (*i.e.*, 104 cfu/100ml)

2.4.2 Analysis of BST Data

The data collected were analyzed for frequency of violations, patterns in fecal source identification, and seasonal impacts. Results of the analyses are presented in the following sections.

2.4.2.1 Bacterial Source Tracking

MapTech, Inc. was contracted to perform an analysis of fecal coliform and *E. coli* concentrations as well as BST. BST is intended to aid in identifying sources (*i.e.*, human, pets, livestock, or wildlife) of fecal contamination in water bodies. Data collected provided insight into the likely sources of fecal contamination, aided in distributing fecal loads from different sources during model calibration, and will improve the chances for success in implementing solutions.

Several procedures are currently under study for use in BST. Virginia has adopted the Antibiotic Resistance Analysis (ARA) methodology implemented by MapTech's EDL. This method was selected because it has been demonstrated to be a reliable procedure for confirming the presence or absence of human, pet, livestock and wildlife sources in watersheds in Virginia. The results were reported as the percentage of isolates acquired from the sample that were identified as originating from either humans, pets, livestock, or wildlife.

The BST results of water samples collected at 3 ambient stations in the Virginia Beach Coastal Area drainage are reported in Tables 2.6 through 2.8. The *E. coli* enumerations are given to indicate the bacteria concentrations at the time of sampling. The proportions reported are formatted to indicate statistical significance (*i.e.*, **BOLD** numbers indicate a statistically significant result). The statistical significance was determined through 2 tests. The first was based on the sample size. A z-test was used to determine if the proportion was significantly different from zero (alpha = 0.10). Second, the rate of false positives was calculated for each source category in each library, and a proportion was not considered significantly different from zero unless it was greater than the false-positive rate plus three standard deviations. Table 2.9 summarizes the results for each station with load-weighted average proportions of bacteria originating from the four source categories. The load-weighted average considers the level of flow in the stream at the time of sampling, the concentration of *E. coli* measured, and the number of bacterial isolates analyzed in the BST analysis. In the case of the tidally influenced station on West Neck Creek (5BWNC010.02), no relevant value of flow was available, so flow was not considered in the calculation. The results at this station seem incongruous with the land uses in the immediate area, however, it is important to remember that this water body gets large inputs from North Landing River and Lynnhaven Bay.

Table 2.6 Summary of bacterial source tracking results from water samples collected in the West Neck Creek (Upper) impairment.

Station	Date	Fecal Coliform (cfu/100 ml)	*E. coli* (cfu/100 ml)	Percent Isolates classified as: Wildlife	Human	Livestock	Pet
5BWNC010.02	7/14/2003	8,900	7,000	0%	0%	**100%**	0%
	8/11/2003	18,000	7,200	0%	0%	**100%**	0%
	9/8/2003	3,200	390	**63%**	0%	**33%**	4%
	10/20/2003	320	40	12%	25%	63%	0%
	11/17/2003	70	40	**29%**	0%	**33%**	**38%**
	12/8/2003	640	820	**25%**	**33%**	**21%**	**21%**
	1/12/2004	150	90	**59%**	12%	8%	**21%**
	2/9/2004	140	100	**12%**	0%	**88%**	0%
	3/15/2004	90	38	**33%**	**17%**	**33%**	**17%**
	4/12/2004	10	140	**38%**	12%	**17%**	**33%**
	5/10/2004	10	90	10%	**38%**	5%	**47%**
	6/14/2004	300	210	4%	0%	**96%**	0%

BOLD type indicates a statistically significant value.

Table 2.7 Summary of bacterial source tracking results from water samples collected in the Nawney Creek impairment.

Station	Date	Fecal Coliform (cfu/100 ml)	*E. coli* (cfu/100 ml)	Percent Isolates classified as: Wildlife	Human	Livestock	Pet
5BNWN000.00	7/14/2003	300	28	0%	0%	**100%**	0%
	8/11/2003	6,500	260	8%	0%	**88%**	4%
	10/20/2003	50	40	0%	0%	100%	0%
	11/17/2003	350	70	**33%**	0%	4%	**63%**
	12/8/2003	120	112	**46%**	**25%**	**29%**	0%
	1/12/2004	50	38	**63%**	**25%**	8%	4%
	2/9/2004	70	50	**21%**	0%	**79%**	0%
	3/15/2004	20	34	**70%**	10%	**15%**	5%
	4/12/2004	50	132	**12%**	**38%**	4%	**46%**
	5/10/2004	20	40	50%	50%	0%	0%
	6/14/2004	240	30	25%	0%	0%	75%

BOLD type indicates a statistically significant value.

Table 2.8 Summary of bacterial source tracking results from water samples collected in the Milldam Creek impairment.

Station	Date	Fecal Coliform (cfu/100 ml)	*E. coli* (cfu/100 ml)	Percent Isolates classified as: Wildlife	Human	Livestock	Pet
5BMLD001.92	7/14/2003	550	110	0%	0%	**100%**	0%
	8/11/2003	2,000	60	17%	17%	33%	33%
	9/8/2003	390	46	**38%**	0%	**62%**	0%
	10/20/2003	80	20	50%	0%	0%	50%
	11/17/2003	10	36	**29%**	0%	10%	**61%**
	12/8/2003	260	148	**17%**	**38%**	12%	**33%**
	1/12/2004	1	20	14%	**29%**	**57%**	0%
	2/9/2004	30	26	**62%**	0%	**38%**	0%
	3/15/2004	140	82	**55%**	8%	**29%**	8%
	4/12/2004	40	58	0%	**50%**	4%	**46%**
	5/10/2004	10	30	25%	0%	63%	12%
	6/14/2004	310	20	0%	0%	0%	100%

BOLD type indicates a statistically significant value.

Table 2.9 Load weighted average proportions of fecal bacteria originating from wildlife, human, livestock, and pet sources.

Station ID	Weighted Averages: Wildlife	Human	Livestock	Pet
5BWNC010.02*	4%	2%	92%	2%
5BNWN000.00	16%	6%	70%	8%
5BMLD001.92	23%	18%	39%	20%

*Flow was not used in the calculation, as no relevant flow values were available.

2.4.2.2 Trend and Seasonal Analyses

In order to improve TMDL allocation scenarios and, therefore, the success of implementation strategies, trend and seasonal analyses were performed on precipitation, discharge, and fecal coliform concentrations. A Seasonal Kendall Test was used to examine long-term trends. The Seasonal Kendall Test ignores seasonal cycles when looking for long-term trends. This improves the chances of finding existing trends in data that are likely to have seasonal patterns. Additionally, trends for specific seasons can be analyzed. For instance, the Seasonal Kendall Test can identify the trend (over many years) in discharge levels during a particular season or month.

A seasonal analysis of precipitation, discharge, and fecal coliform concentration data were conducted using the Mood Median Test. This test was used to compare median values of precipitation, discharge, and fecal coliform concentrations in each month. Significant differences between months within years were reported.

2.4.2.3 Fecal Coliform Concentrations

Water quality monitoring data collected by VADEQ were described in section 2.2.1.1. The trend analysis was conducted on data, if sufficient, collected at stations used in TMDL assessment. An overall, long-term decrease in fecal coliform concentrations was detected at stations 5BNWN000.00, 5BNWN001.84, and 7LOB001.79. The slope of this decrease at 5BNWN000.00 was estimated at –12.50 cfu/100 ml. At 5BNWN001.84 the slope was estimated at –16.67 cfu/100 ml. At 7LOB001.79 the slope was estimated at –12.22 cfu/100 ml. Remaining stations had no overall trend (Table 2.10).

Table 2.10 Summary of trend analysis on fecal coliform (cfu).

Station	Mean	Median	Max	Min	SD[1]	N[2]	Significant Trend[3]
5BMLD001.92	405.29	100	8,000	49	997.56	82	No Trend
5BNWN000.00	593.33	200	4,700	25	884.62	99	-12.50
5BNWN001.84	530.51	220	2,900	25	582.36	99	-16.67
5BWNC003.65	307.57	100	4,200	25	538.84	101	No Trend
5BWNC010.02	715.07	350	2,000	22	669.40	86	No Trend
7LOB001.79	1,043.48	540	16,000	11	1,924.50	148	-12.22
7LOB003.70	1,166.72	1,600	1,600	95	567.20	32	No Trend
7XBO001.30	572.86	350	1,700	17	563.39	58	No Trend

[1]SD: standard deviation, [2]N: number of sample measurements, [3]A number in the significant trend column represents the Seasonal-Kendall estimated slope, "--" insufficient data

Differences in mean monthly fecal coliform concentration for stations 5BNWN001.84 and 7LOB001.79 are indicated in Tables 2.11 and 2.12 respectively. The remaining stations had no seasonality effect. Fecal coliform concentrations in months with the same median group letter are not significantly different from each other at a 95% significance level. For example, in Table 2.11, June and August are both in median group "B" and are not significantly different from each other. Fecal coliform concentrations in months with multiple groups are the result of the 95% confidence interval, for that month, overlapping more than one median group. For example, fecal coliform values during the months of January, February, April, May, July, September, October, November, and December are classified in both median groups "A" and "B" and are not significantly different than either group.

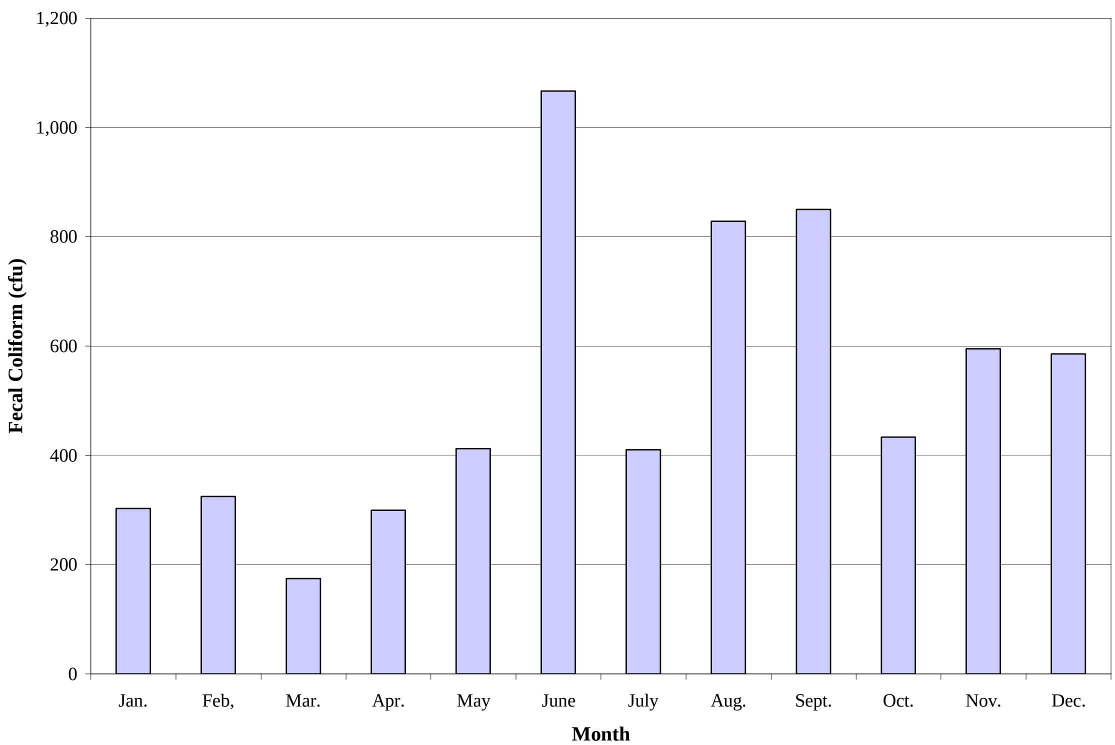


Figure 2.11 Summary of the Mood Median Test on mean monthly fecal coliform counts at station 5BNWN001.84 (p=0.031).

Table 2.11 Summary of the Mood Median Test on mean monthly fecal coliform counts at station 5BNWN001.84 (p=0.031).

Month	Mean (cfu)	Minimum (cfu)	Maximum (cfu)	Median Groups	
January	302.86	100	900	A	B
February	325.00	100	1,100	A	B
March	174.50	25	600	A	
April	300.00	100	1,100	A	B
May	412.50	100	1,500	A	B
June	1,066.67	100	2,900		B
July	410.50	25	2,200	A	B
August	828.57	200	1,600		B
September	833.33	100	2,000	A	B
October	433.33	100	1,600	A	B
November	595.00	100	1,700	A	B
December	585.71	100	1,400	A	B

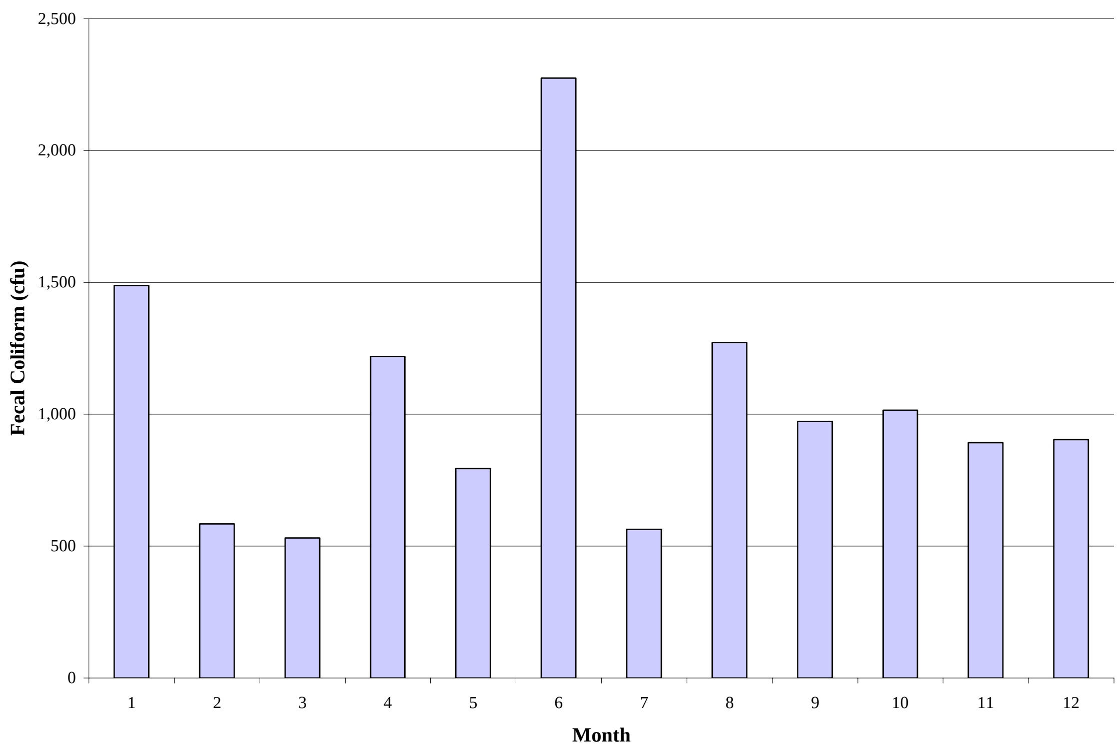


Figure 2.12 Summary of the Mood Median Test on mean monthly fecal coliform counts at station 7LOB001.79 (p=0.038).

Table 2.12 Summary of the Mood Median Test on mean monthly fecal coliform counts at station 7LOB001.79 (p=0.038).

Month	Mean (cfu)	Minimum (cfu)	Maximum (cfu)	Median Groups	
January	1,488.80	13	16,000	A	B
February	584.22	49	1,600	A	B
March	531.67	25	1,600	A	B
April	1,218.83	11	3,500	A	B
May	793.69	78	3,500	A	B
June	2,274.17	240	16,000	A	B
July	563.84	130	1,600	A	
August	1,271.818	540	1,600		B
September	972.57	26	3,500	A	B
October	1,016.00	120	1,600	A	B
November	892.93	70	3,500	A	B
December	903.90	79	1,700	A	B

2.4.2.4 Summary of In-stream Water Quality Monitoring Data

Wide ranges of fecal coliform concentrations have been recorded in the watershed. Concentrations reported during TMDL development were within the range of historical values reported by VADEQ during TMDL assessment. Exceedances of the instantaneous standard were reported in all flow regimes, leaving no apparent relationship between flow and water quality.

3. SOURCE ASSESSMENT

The TMDL development described in this report includes examination of all potential sources of fecal coliform in the Virginia Beach Coastal Area. The source assessment was used as the basis of model development and ultimate analysis of TMDL allocation options. In evaluation of the sources, loads were characterized by the best available information, landowner input, literature values, and local management agencies. This section documents the available information and interpretation for the analysis. The source assessment chapter is organized into point and nonpoint sections. The representation of the following sources in the model is discussed in Section 4.

3.1 Watershed Characterization

The National Land Cover Data (NLCD) produced cooperatively between the U.S. Geological Survey (USGS) and U.S. Environmental Protection Agency (EPA) was utilized for this study. The collaborative effort to produce this dataset is part of a Multi-Resolution Land Characteristics (MRLC) Consortium project led by four U.S. government agencies: EPA, USGS, the Department of the Interior National Biological Service (NBS), and the National Oceanic and Atmospheric Administration (NOAA). Using 30-meter resolution Landsat 5 Thematic Mapper (TM) satellite images taken between 1990 and 1994, digital land use coverage was developed identifying up to 21 possible land use types. Classification, interpretation, and verification of the land cover dataset involved several data sources when available including: aerial photography; soils data; population and housing density data; state or regional land cover data sets; USGS land use and land cover (LUDA) data; 3-arc second Digital Terrain Elevation Data (DTED) and derived slope, aspect and shaded relief; and National Wetlands Inventory (NWI) data. Approximate acreages and landuse proportions for each impaired segment are given in Table 3.1 and shown in Figure 3.1.

Table 3.1 Contributing landuse area for impaired segments in the Virginia Beach Coastal Area.

	Landuse								
Impaired Segment	**Water (acres)**	**Residential (acres)**	**Commercial & Services (acres)**	**Barren (acres)**	**Woodland (acres)**	**Pasture (acres)**	**Cropland (acres)**	**Wetlands (acres)**	**Livestock Access (acres)**
London Bridge Creek	267	3,037	374	559	637	191	342	419	25
Milldam Creek	112	0	0	0	140	53	636	1,513	10
Nawney Creek	119	132	42	0	202	702	2,421	1,063	77
West Neck (Middle)	101	23	8	8	446	126	1,511	1,106	16
West Neck (Upper)	446	2,966	1,407	426	1,279	731	1,521	2,166	156

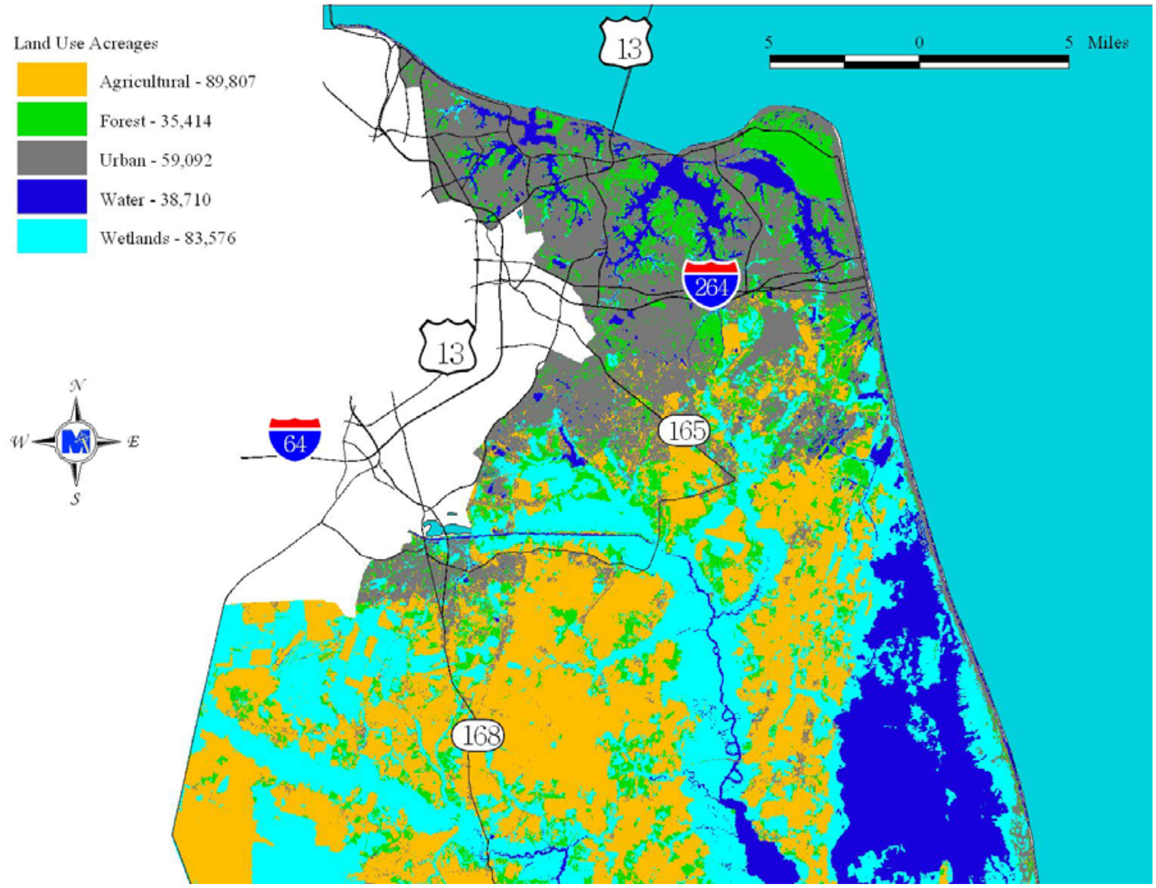


Figure 3.1 Landuses in the Virginia Beach Coastal Area.

The estimated human population within the impaired drainage areas in 2004 is 77,420 with 14,388 dogs and 16,112 cats associated with this population. Table 1.2 lists agricultural production rankings for the City of Virginia Beach in the Virginia Beach Coastal Area compared to all counties in Virginia (Virginia Agricultural Statistics, 2002). This coastal area is home to numerous species of wildlife, including mammals (*e.g.,* beaver, raccoon, white-tailed deer) and birds (*e.g.,* wood duck, Canada goose) (VDGIF, 2004), (Table 3.3).

Table 3.2 Agricultural production rankings for Virginia Beach in the Virginia Beach Coastal Area compared to all counties in Virginia.

City	Production Rankings Compared to Other Counties in Virginia*						
	Cattle & Calves	Dairy	Beef	Horses	Layers	Broilers	Swine
Virginia Beach	93	N/A	N/A	49	47	N/A	9

*VASS, 2002.

Table 3.3 Number of wildlife species, mammal types, and bird types inhabiting Virginia Beach within the Virginia Beach Coastal Area.

City	Number of Wildlife Species	Number of Mammal Types	Number of Bird Types
Virginia Beach	557	49	287

*VDGIF, 2004.

For the period from 1953 to 2004, the portion of the Virginia Beach Coastal Area near the Back Bay Wildlife Refuge, Virginia received an average annual precipitation of approximately 45.08 inches, with 56% of the precipitation occurring during the May through October growing season (SERCC, 2004). Average annual snowfall is 3.1 inches, with the highest snowfall occurring during January (SERCC, 2004). Average annual daily temperature is 59.9 ºF. The highest average daily temperature of 85.9 ºF occurs in July, while the lowest average daily temperature of 31.7 ºF occurs in January (SERCC, 2004).

3.2 Assessment of Point Sources

Two (2) point sources are permitted in the Virginia Beach Coastal Area through the Virginia Pollutant Discharge Elimination System (VPDES). Both point sources are MS4 permits, and are located in the City of Virginia Beach (Table 3.4). Permitted point discharges (with the exception of MS4 permits) that may contain pathogens associated with fecal matter are required to maintain a fecal coliform concentration below 200 cfu/100 ml. Since the MS4 systems are not permitted for fecal control, they do not use chlorination practices.

Table 3.5 summarizes data from VPDES Confined Animal Feeding Operations (CAFO) and from Virginia Pollution Abatement (VPA) facilities along with the streams that receive potential runoff from these facilities. Figure 3.2 shows the VPA and CAFO locations. These permitted sources don’t have direct discharges to waterways but runoff from the area could contain fecal coliform and *E. coli* bacteria.

Table 3.4 Summary of VPDES permitted point sources in the Virginia Beach Coastal Area.

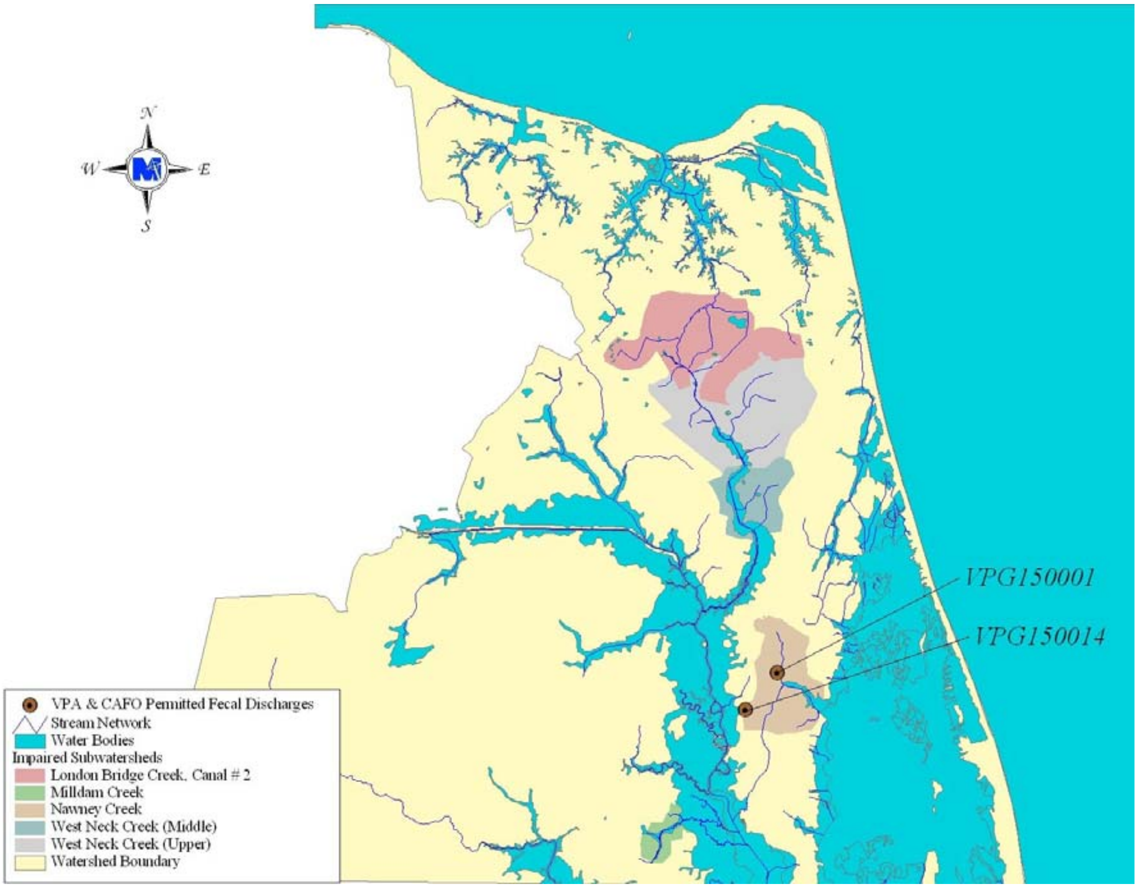
Receiving Water	Facility Name	Permit No	Design Flow (MGD)	Permitted For Fecal Control	Data Availability
West Neck Creek, London Bridge Creek, Wolfsnare Creek, Great Neck Creek and Redwing Lake	MS4 - US Naval Station Oceana	VAR040043	NA	ND	ND
West Neck Creek, London Bridge Creek and other waters within the City of Virginia Beach	MS4 – City of Virginia Beach	VA0088676	NA	ND	ND

ND – no data, facility not required to submit monitoring data.
NA – Not available.

Table 3.5 Summary of VPA and CAFO permits in the Virginia Beach Coastal Area.

Watershed	Facility Name	Permit No	Permit Type	Permitted For Fecal Control	Data Availability
Nawney Creek	Barry D. Knight Hog Farm	VPG150001**	CAFO	No	ND
Nawney Creek	David S. Salmons	VPG150014	CAFO	No	ND

** Farm no longer active.
ND – no data, facility not required to submit monitoring data.



*CAFO under permit #VPG150001 is no longer in operation as of 2001.

Figure 3.2 Location of VPA and CAFO permitted point sources in the Albemarle and Lynnhaven –Poquoson River Watersheds.

3.3 Assessment of Nonpoint Sources

In the Virginia Beach Coastal Area, both urban and rural nonpoint sources of fecal coliform bacteria were considered. Sources include residential sewage treatment systems, land application of waste (livestock and biosolids), livestock, wildlife, and pets. Sources were identified and enumerated. MapTech collected samples of fecal coliform sources (*i.e.*, wildlife, livestock, pets, and human waste) and enumerated the density of fecal coliform bacteria to support the modeling process and to expand the database of known fecal coliform sources for purposes of bacterial source tracking (Section 2.4.2.1). Where appropriate, spatial distribution of sources was also determined.

3.3.1 Private Residential Sewage Treatment

In the U.S. Census questionnaires, housing occupants were asked which type of sewage disposal existed. Houses can be connected to a public sanitary sewer, a septic tank, or a cesspool, or the sewage is disposed of in some other way. The Census category “Other Means” includes the houses that dispose of sewage other than by public sanitary sewer or a private septic system. The houses included in this category are assumed to be disposing of sewage via a pit-privy or through the use of a straight pipe (direct stream outfall). Population, housing units, and type of sewage treatment from U.S. Census Bureau were calculated using GIS (Table 3.6).

Sanitary sewers are piping systems designed to collect wastewater from individual homes and businesses and carry it to a wastewater treatment plant. Sewer systems are designed to carry a specific "peak flow" volume of wastewater to the treatment plant. Within this design parameter, sanitary collection systems are not expected to overflow, surcharge or otherwise release sewage before their waste load is successfully delivered to the wastewater treatment plant.

When the flow of wastewater exceeds the design capacity, the collection system will "back up" and sewage discharges through the nearest escape location. These discharges into the environment are called overflows. Wastewater can also enter the environment through exfiltration caused by line cracks, joint gaps, or breaks in the piping system.

Typical private residential sewage treatment systems (septic systems) consist of a septic tank, distribution box, and a drainage field. Waste from the household flows first to the septic tank, where solids settle out and are periodically removed by a septic tank pump-out. The liquid portion of the waste (effluent) flows to the distribution box, where it is distributed among several buried, perforated pipes that comprise the drainage field. Once in the soil, the effluent flows downward to groundwater, laterally to surface water, and/or upward to the soil surface. Removal of fecal coliform is accomplished primarily by die-off during the time between introduction to the septic system and eventual introduction to naturally occurring waters. Properly designed, installed, and functioning septic systems contribute virtually no fecal coliform to surface waters.

A septic failure occurs when a drain field has inadequate drainage or a "break", such that effluent flows directly to the soil surface, bypassing travel through the soil profile. In this situation, the effluent is either available to be washed into waterways during runoff events or is directly deposited in-stream due to proximity. A survey of septic pump-out contractors performed by MapTech showed that failures were more likely to occur in the winter-spring months than in the summer-fall months, and that a higher percentage of system failures were reported because of a back-up to the household than because of a failure noticed in the yard.

MapTech sampled waste from septic tank pump-outs and found an average fecal coliform density of 1,040,000 cfu/100 ml (MapTech, 2001). An average fecal coliform density for human waste of 13,000,000 cfu/g and a total waste load of 75 gal/day/person was reported by Geldreich (1978).

Table 3.6 Human population, housing units, houses on sanitary sewer, septic systems, and other sewage disposal systems for 2004 in areas contributing to impaired segments in the Virginia Beach Coastal Area.

Impaired Segment	Population	Housing Units	Sanitary Sewer	Septic Systems	Other *
London Bridge Creek/ Canal #2	42,792	15,404	15,323	77	4
Milldam Creek	151	57	1	51	5
Nawney Creek	703	264	0	260	4
West Neck Creek (Middle)	4,431	1,517	539	966	12
West Neck Creek (Upper)	29,343	9,703	9,223	478	2

* Houses with sewage disposal systems other than sanitary sewer and septic systems.

3.3.2 Biosolids

Biosolids from one wastewater source, Hampton Roads Sanitary District (HRSD), have been applied to agricultural lands in the Virginia Beach Coastal Area (Table 3.7). Between 1997 and 2003 an average of 477 dry tons were applied per year to the watershed. Table 3.8 list the acres permitted for biosolids application, number of acres biosolids applied to and dry tons of biosolids applied to impairments in the Virginia Beach Coastal Area. The application of biosolids to agricultural lands is strictly regulated in Virginia (VDH, 1997). Biosolids are required to be spread according to sound agronomic requirements with consideration for topography and hydrology. Class B biosolids may not have a fecal coliform density greater than 1,995,262 cfu/g (total solids). Application rates must be limited to a maximum of 15 dry tons/acre per three-year period.

Table 3.7 Source and application of dry biosolids within the Virginia Beach Coastal Area.

Source of Biosolids	Dry Tons Applied In 1997	1998	1999	2000	2001	2002	2003
HRSD	438.40	148.70	1,148.10	1,600.90	0	0	0
Total	438.40	148.70	1,148.10	1,600.90	0	0	0

Table 3.8 Acres permitted for biosolids application, number of acres biosolids applied to, dry tons of biosolids applied in the Virginia Beach Coastal Area.

Impairment	Acres Permitted	Acres Applied (1997-2003)	Dry Tons Applied (1997-2003)
London Bridge/Canal #2	162.8	143.1	665.6
Milldam Creek	326.8	129.2	258.4
Nawney Creek	606.00	585.9	1,345.4
West Neck (Middle)	88.00	88.00	116.5
West Neck (Upper)	170.5	56.1	195.5

3.3.3 Pets

Among pets, cats and dogs are the predominant contributors of fecal coliform in the Virginia Beach Coastal Area and were the only pets considered in this analysis. Cat and dog populations were derived from American Veterinary Medical Association Center for Information Management demographics in 1997. Dog waste load was reported by Weiskel et al. (1996), while cat waste load was measured. Fecal coliform density for dogs and cats was measured from samples collected throughout Virginia by MapTech. A summary of the data collected is given in Table 3.9. Table 3.10 lists the domestic animal populations for impairments in the Virginia Beach Coastal Area.

Table 3.9 Domestic animal population density, waste load, and fecal coliform density.

Type	Population Density (an/house)	Waste load (g/an-day)	FC Density (cfu/g)
Dog	0.534	450	480,000
Cat	0.598	19.4	9

Table 3.10 Estimated domestic animal populations in areas contributing to impaired segments in the Virginia Beach Coastal Area.

Impaired Segment	Dogs	Cats
London Bridge Creek & Canal #2	8,226	9,211
Milldam Creek	30	34
Nawney Creek	141	158
West Neck Creek (Middle)	810	907
West Neck Creek (Upper)	5,181	5,802

3.3.4 Livestock

The predominant types of livestock in the impaired streams of the Virginia Beach Coastal Area are swine and horses although all types of livestock identified were considered in modeling the watershed. Operations range from small to large in size, including operations permitted under either VPA or CAFO regulations. Table 3.5 gives a summary of these permitted operations in the drainage area of impaired streams in the Virginia Beach Coastal Area. Table 3.11 gives a summary of livestock populations in the watershed study area during the period for source assessment, organized by impairment. Animal populations were based on communication with Virginia Department of Conservation and Recreation (DCR), USDA Natural Resources Conservation Service (NRCS), Virginia Dare Soil and Water Conservation District, Virginia Beach Department of Agriculture, USDA's Farm Services Agency, local extension agents, watershed visits, and verbal communication with farmers. Values of fecal coliform density of livestock sources were based on sampling performed by MapTech (MapTech, 1999a). Reported manure production rates for livestock were taken from American Society of Agricultural Engineers (1998). A summary of fecal coliform density values and manure production rates is presented in Table 3.12.

Table 3.11 Livestock populations in areas contributing to impaired segments in the Virginia Beach Coastal Area.

Impaired Segment	Horse	Swine	Sheep
London Bridge Creek & Canal #2	59	0	2
Milldam Creek	5	0	0
Nawney Creek	15	3,727	0
West Neck Creek (Middle)	10	0	0
West Neck Creek (Upper)	140	0	0

Table 3.12 Average fecal coliform densities and waste loads associated with livestock.

Type	Waste Load (lb/d/an)	Fecal Coliform Density (cfu/g)
Horse (1,000 lb)	51.0	94,000
Swine (135 lb)	11.3	400,000
Swine Lagoon	N/A	95,300[1]
Sheep (60 lb)	2.4	43,000

[1]units are cfu/100ml

Fecal coliform produced by livestock can enter surface waters through four pathways. First, waste produced by animals in confinement is typically collected, stored, and applied to the landscape (*e.g.,* pasture and cropland), where it is available for wash-off during a runoff-producing rainfall event. Table 3.13 shows the average percentage of collected livestock waste that is applied throughout the year. Second, grazing livestock deposit manure directly on the land where it is available for wash-off during a runoff-producing rainfall event. Third, livestock with access to streams occasionally deposit manure directly in streams. Fourth, some animal confinement facilities have drainage systems that divert wash-water and waste directly to drainage ways or streams.

Table 3.13 Average percentage of collected livestock waste applied throughout year.

Month	Applied % of Total	Landuse
	Swine	
January	0.00	Cropland
February	0.00	Cropland
March	20.00	Cropland
April	20.00	Cropland
May	20.00	Cropland
June	0.00	Pasture
July	0.00	Pasture
August	0.00	Pasture
September	0.00	Cropland
October	20.00	Cropland
November	20.00	Cropland
December	0.00	Cropland

All livestock were expected to deposit some portion of waste on land areas. Horses and sheep were assumed to be in pasture 100% of the time.

3.3.5 Wildlife

The predominant wildlife species in the Virginia Beach Coastal Area were determined through consultation with wildlife biologists from the Virginia Department of Game and Inland Fisheries (VDGIF), United States Fish and Wildlife Service (FWS), citizens from the watershed, source sampling, and site visits. Population densities were calculated from data provided by VDGIF and FWS, as well as The Center for Conservation Biology, and are listed in Table 3.14 (Boettcher, 2004; Bidrowski, 2004; Farrar, 2003; Fies 2004; Knox, 2004; Raftovich, 2004; Rose and Cranford, 1987; and Watts, 2004). The numbers of animals estimated to be in the Virginia Beach Coastal Area are reported in Table 3.15. Habitat and seasonal food preferences were determined based on information obtained from The Fire Effects Information System (1999) and VDGIF (Costanzo, 2003; Norman, 2003; Rose and Cranford, 1987; and VDGIF, 1999). Waste loads were comprised from literature values and discussion with VDGIF personnel (ASAE, 1998; Bidrowski, 2003; Costanzo, 2003; Weiskel et al., 1996, and Yagow, 1999; Gould and Fletcher, 1978). Table 3.16 summarizes the habitat and fecal production information that was obtained. Where available, fecal coliform densities were based on sampling of wildlife scat performed by MapTech. The only value that was not obtained from MapTech sampling in the watershed was for beaver. The fecal coliform density of beaver waste was taken from sampling done for the Mountain Run TMDL development (Yagow, 1999). Percentage of time spent in stream access areas and percentage of waste directly deposited to streams was based on habitat information and location of feces during source sampling. Fecal coliform densities and estimated percentages of time spent in stream access areas (*i.e.*, within 100 feet of stream) are reported in Table 3.17.

Table 3.14 Wildlife population density.

County/City	Deer (an/ac of habitat)	Goose (an/ac)	Duck (an/ac)	Muskrat (an/ac of habitat)	Raccoon (an/ac of habitat)	Beaver (an/mi of stream)	Seagull (an/acre of habitat)
Virginia Beach	0.015	0.003	0.009	2.75	0.0703	4.8	0.059

Table 3.15 Wildlife populations in the Virginia Beach Coastal Area.

Impairment	Deer	Goose	Duck	Muskrat	Raccoon	Beaver	Gull
London Bridge/Canal #2	43	11	30	740	271	53	104
Milldam Creek	20	10	26	118	91	42	55
Nawney Creek	60	14	38	321	272	34	113
West Neck (Middle)	42	15	39	372	188	39	93
West Neck (Upper)	94	27	71	733	580	58	233

Table 3.16 Wildlife fecal production rates and habitat.

Animal	Waste Load (g/an-day)	Habitat
Raccoon	450	Primary = region within 600 ft of perennial streams Secondary = region between 601 and 7,920 ft from perennial streams Infrequent/Seldom = rest of watershed area including waterbodies (lakes, ponds)
Muskrat	100	Primary = waterbodies, and land area within 66 ft from the edge of perennial streams, and waterbodies Secondary = region between 67 and 308 ft from perennial streams, and waterbodies Infrequent/Seldom = rest of the watershed area
Beaver[1]	200	Primary = Perennial streams. Generally flat slope regions (slow moving water), food sources nearby (corn, forest, younger trees) Infrequent/Seldom = rest of the watershed area
Deer	772	Primary = forested, harvested forest land, orchards, grazed woodland, urban grassland, cropland, pasture, wetlands, transitional land Secondary = low density residential, medium density residential Infrequent/Seldom = remaining landuse areas
Goose[2]	225	Primary = waterbodies, and land area within 66 ft from the edge of perennial streams, and waterbodies Secondary = region between 67 and 308 ft from perennial streams, and waterbodies Infrequent/Seldom = rest of the watershed area
Mallard	150	Primary = waterbodies, and land area within 66 ft from the edge of perennial streams, and waterbodies Secondary = region between 67 and 308 ft from perennial streams, and waterbodies Infrequent/Seldom = rest of the watershed area
Gull	19.9	Primary = waterbodies, and land area within 66 ft from the edge of perennial streams, and landfills Secondary = region between 67 and 308 ft from perennial streams, and waterbodies Infrequent/Seldom = rest of the watershed area

1 Beaver waste load was calculated as twice that of muskrat, based on field observations.
2 Goose waste load was calculated as 50% greater than that of duck, based on field observations and conversation with Gary Costanzo (Costanzo, 2003).

Table 3.17 Average fecal coliform densities and percentage of time spent in stream access areas for wildlife.

Animal Type	Fecal Coliform Density (cfu/g)	Portion of Day in Stream Access Areas (%)
Raccoon	2,100,000	5
Muskrat	1,900,000	90
Beaver	1,000	100
Deer	380,000	5
Goose	250,000	50
Duck	3,500	75
Gull	120,000,000	65

4. MODELING PROCEDURE: LINKING THE SOURCES TO THE ENDPOINT

Establishing the relationship between in-stream water quality and the source loadings is a critical component of TMDL development. It allows for the evaluation of management options that will achieve the desired water quality endpoint. In the development of TMDLs in the Virginia Beach Coastal Area, the relationship was defined through computer modeling based on data collected throughout the watershed. Monitored flow and water quality data were then used to verify that the relationships developed through modeling were accurate. There are four basic steps in the development and use of a water quality model: model selection, source assessment, selection of a representative modeling period, model calibration, model validation, and model simulation. In the case of this TMDL, due to the limited amount of data available, it was determined to be most appropriate to utilize all data for the purposes of calibration, rather than to parse the data into smaller subsets for calibration and validation.

Model selection involves identifying an approved model that is capable of simulating the pollutants of interest with the available data. Source assessment involves identifying and quantifying the potential sources of pollutants in the watershed. Selection of a representative period involves the identification of a time period that accounts for critical conditions associated with all potential sources within the watershed. Calibration is the process of comparing modeled data to observed data and making appropriate adjustments to model parameters to minimize the error between observed and simulated events. Once a suitable model is constructed, the model is then used to predict the effects of current loadings and potential management practices on water quality. In this section, the selection of modeling tools, source assessment, selection of a representative period, calibration, and model application are discussed.

4.1 Modeling Framework Selection

The Virginia Beach Coastal Area contains both wind-driven and tidally driven systems, and thus requires a very robust and versatile modeling platform. The West Neck Creek, London Bridge Creek and Canal #2, Nawney Creek, and Milldam Creek are all described as “wind tidal tributaries” and share hydrologic connectivity with other wind tidal, and lunar tidal bodies of water (City of Virginia Beach, 2003). However, these five creeks of interest are basically riverine in structure, and are known to receive substantial flow inputs from storm water runoff in their contributing areas.

The USGS Hydrologic Simulation Program - Fortran (HSPF) water quality model was selected as the modeling framework to simulate existing conditions and to perform TMDL allocations in tidal areas. The HSPF model is a continuous simulation model that can account for NPS pollutants in runoff, as well as pollutants entering the flow channel from point sources. In establishing the existing and allocation conditions, seasonal variations in hydrology, climatic conditions, and watershed activities were explicitly accounted for in the model. The use of HSPF allowed consideration of seasonal aspects of precipitation patterns within the watershed. Due to the complex landuses and tributary networks of the tidal areas, HSPF is well suited for providing runoff inputs to a suitable tidal model, provided that the tidal model possesses the ability to receive temporally and spatially varying inputs from HSPF. CE-QUAL-W2 (Army Corps of Engineers, 2003) meets the requirements of modeling this system, including time varying point and non-point sources, wind, tides, a first order decay-based general quality constituent component (including a settling routine for fecal coliform if desired) and continuous simulation. The model’s main limitation is its lateral averaging, which is why it is preferred for use with narrow bodies of water such as those in the Virginia Beach Coastal Area. The documented model selection process can be seen in “Tidal Estuary Model Recommendation for use in the Chowan and Tennessee River TMDL,” prepared by MapTech, Inc. and submitted in July 2004 to VADEQ.

The HSPF model simulates a watershed by dividing it up into a network of stream segments (referred to in the model as RCHRES), impervious land areas (IMPLND) and pervious land areas (PERLND). Each subwatershed contains a single RCHRES, modeled as an open channel, and numerous PERLNDs and IMPLNDs, representing the various landuses in that subwatershed. Water and pollutants from the land segments in a given subwatershed flow into the RCHRES in that subwatershed. Point discharges and withdrawals of water and pollutants are simulated as flowing directly to or withdrawing from a particular RCHRES as well. Water and pollutants from a given RCHRES flow into the next downstream RCHRES. The network of RCHRESs is constructed to mirror the configuration of the stream segments found in the physical world. Therefore, activities simulated in one impaired stream segment affect the water quality downstream in the model.

4.2 Model Setup

To adequately represent the spatial variation in the watershed, the Virginia Beach Coastal drainage area was divided into forty-four (44) subwatersheds (Figure 4.1) for the purpose of modeling hydrology. The rationale for choosing these subwatersheds was based on the availability of water quality data and the limitations of the HSPF model. Water quality data (*i.e.,* fecal coliform concentrations) are available at specific locations throughout the watershed. Subwatershed outlets were chosen to coincide with these monitoring stations, since output from the model can only be obtained at the modeled subwatershed outlets (Figure 4.1 and Table 4.1). In an effort to standardize modeling efforts across the state, VADEQ has required that fecal bacteria models be run at a 1-hour time-step. The HSPF model requires that the time of concentration in any subwatershed be greater than the time-step being used for the model. These modeling constraints as well as the desire to maintain a spatial distribution of watershed characteristics and associated parameters were considered in the delineation of subwatersheds. The spatial division of the watershed allowed for a more refined representation of pollutant sources, and a more realistic description of hydrologic factors in the watershed.

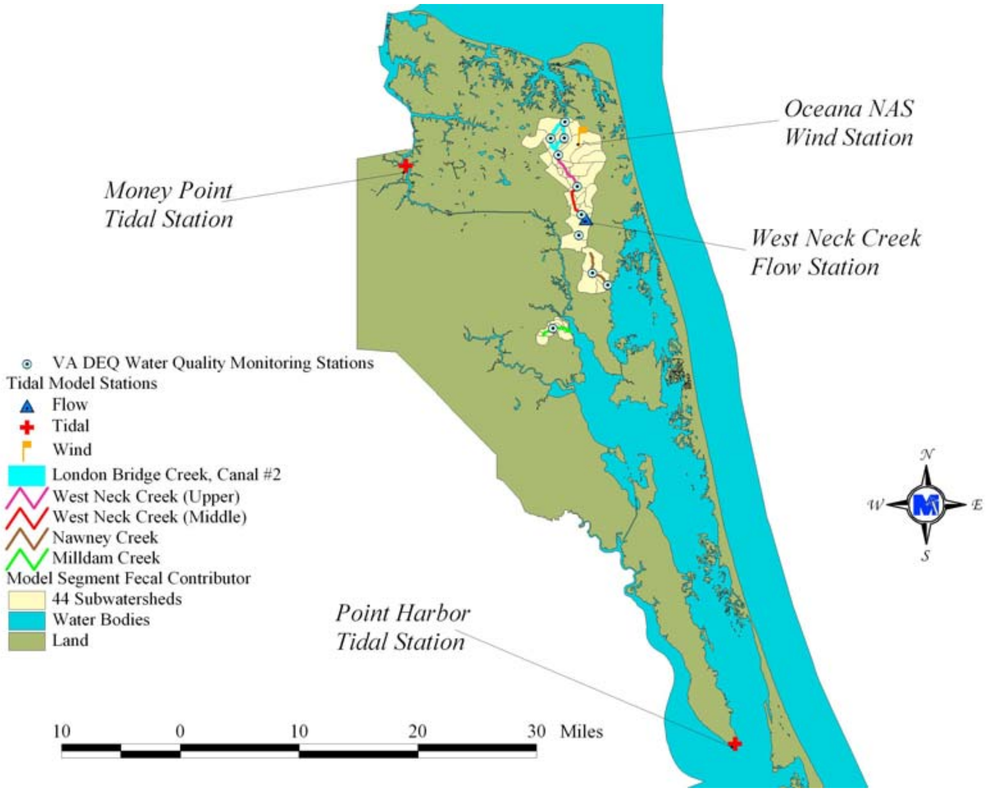


Figure 4.1 Subwatersheds delineated for modeling and location of VADEQ water quality monitoring stations and USGS Gaging Station in the Virginia Beach Coastal Area (Model Segment shown in yellow).

Table 4.1 VADEQ monitoring stations and corresponding reaches in the Virginia Beach Coastal Area.

Impairment	Station Number	Reach Number
London Bridge Creek	7LOB003.70	2
London Bridge Creek	7LOB001.79	6
Canal #2	7XBO001.30	5
Milldam Creek	5BMLD001.92	35
Nawney Creek	5BNWN001.84	29
Nawney Creek	5BNWN000.00	30
West Neck Creek (Middle)	5BWNC003.65	25
West Neck Creek (Upper)	5BWNC010.02	11

Using aerial photographs, MRLC identified 14 landuse types in the watershed. For this model the 14 landuse types were consolidated into 10 categories (Table 4.2) based on similarities in hydrologic and waste application/production features. Within each subwatershed, 10 landuse types were represented. Each landuse had parameters associated with it that described the hydrology of the area (*e.g.,* average slope length) and the behavior of pollutants (*e.g.,* fecal coliform accumulation rate). Table 4.3 shows the consolidated landuse types and the area existing in each impairment. These landuse types are represented in HSPF as pervious land segments (PERLNDs) and impervious land segments (IMPLNDs). Impervious areas in the watershed are represented in three IMPLND types, while there are nine PERLND types, each with parameters describing a particular landuse (Table 4.2). Some IMPLND and PERLND parameters (*e.g.,* slope length) vary with the particular subwatershed in which they are located. Others vary with season (*e.g.,* upper zone storage) to account for plant growth, die-off, and removal.

Table 4.2 Consolidation of MRLC landuse categories for the Virginia Beach Coastal Area

TMDL Landuse Categories	Pervious/Impervious (Percentage)	MRLC Landuse Classifications (Class No.)
Water	Impervious (100%)	Open Water (11)
Residential*	Pervious (80%) Impervious (20%)	Low Intensity Residential (21) High Intensity Residential (22) Urban/Recreational Grasses (85)
Commercial and Services	Pervious (30%) Impervious (70%)	Commercial/Industrial/Transportation (23)
Barren	Pervious (100%)	Quarries/Strip Mines/Gravel Pits (32) Transitional (33)
Woodland	Pervious (100%)	Deciduous Forest (41) Evergreen Forest (42) Mixed Forest (43)
Pasture	Pervious (100%)	Pasture/Hay (81)
Cropland	Pervious (100%)	Row Crops (82)
Wetlands	Pervious (100%)	Woody Wetlands (91) Emergent Herbaceous Wetlands (92)
Livestock Access	Pervious (100%)	Pasture/Hay (81)

*TMDL landuse categories were divided into Low Density Residential (includes MRLC class 21 and 85), and High Density Residential.

Table 4.3 Spatial distribution of landuse types in the tidal model for the Virginia Beach Coastal Area.

Impaired Segment	Landuse									
	Water (ac)	Low Density Residential (ac)	High Density Residential (ac)	Commercial (ac)	Barren (ac)	Woodland (ac)	Pasture (ac)	Cropland (ac)	Wetlands (ac)	Livestock Access (ac)
London Bridge & Canal #2	317	2,506	902	1,235	654	905	460	580	671	63
Milldam Creek	110	10	0	0	0	137	52	634	1,510	11
Nawney Creek	117	113	70	41	0	202	706	2,368	1,069	72
West Neck Creek (Middle)	104	460	10	9	9	446	127	1,061	1,091	16
West Neck Creek (Upper)	383	1,396	1,197	546	336	1,015	465	1,288	1,915	119

Die-off of fecal coliform can be handled implicitly or explicitly. For land-applied fecal matter (mechanically applied and deposited directly), die-off was addressed implicitly through monitoring and modeling. Samples of collected waste prior to land application (*i.e.*, dairy waste from loafing areas) were collected and analyzed by MapTech. Therefore, die-off is implicitly accounted for through the sample analysis. Die-off occurring in the field was represented implicitly through model parameters such as the maximum accumulation and the 90% wash off rate, which were adjusted during the calibration of the model. These parameters were assumed to represent not only the delivery mechanisms, but the bacteria die-off as well. Once the fecal coliform entered the stream, the general decay module of HSPF was incorporated, thereby explicitly addressing the die-off rate. The general decay module uses a first order decay function to simulate die-off.

4.3 Source Representation

Both point and nonpoint sources can be represented in the model. In general, point sources are added to the model as a time-series of pollutant and flow inputs to the stream. Land-based nonpoint sources are represented as an accumulation of pollutants on land, where some portion is available for transport in runoff. The amount of accumulation and availability for transport vary with landuse type and season. The model allows for a maximum accumulation to be specified. The maximum accumulation was adjusted seasonally to account for changes in die-off rates, which are dependent on temperature and moisture conditions. Some nonpoint sources, rather than being land-based, are represented as being deposited directly to the stream (*e.g.*, animal defecation in stream). These sources are modeled similarly to point sources, as they do not require a runoff event for delivery to the stream. These sources are primarily due to animal activity, which varies with the time of day. Direct depositions by nocturnal animals were modeled as being deposited from 6:00 PM to 6:00 AM, and direct depositions by diurnal animals were modeled as being deposited from 6:00 AM to 6:00 PM. Once in stream, die-off is represented by a first-order exponential equation.

Much of the data used to develop the model inputs for modeling water quality is time-dependent (*e.g.*, population). Depending on the timeframe of the simulation being run, different numbers should be used. Data representing 2002 were used for the water quality calibration period. Data representing 2004 were used for the allocation runs in order to represent current conditions.

4.3.1 Point Sources

There are two permitted point discharges in the Virginia Beach Coastal Area. No data is available as to whether either of these facilities are permitted for fecal control, (see Table 3.4). Nonpoint sources of pollution that were not driven by runoff (*e.g.*, direct deposition of fecal matter to the the stream by wildlife) were modeled similarly to point sources. These sources, as well as land-based sources, are identified in the following sections.

4.3.2 Private Residential Sewage Treatment

The number of septic systems in the 44 subwatersheds modeled for water quality in the Virginia Beach Coastal Area was calculated by overlaying U.S. Census Bureau data (USCB, 1990; USCB, 2000) with the watershed to enumerate the septic systems. Each residential landuse area was assigned a number of septic systems based on census data. A total of 1,182 septic systems were estimated in the Virginia Beach Coastal Area in 1995. During allocation runs, the number of households was projected to 2004, based on current growth rates (USCB, 2000) resulting in 1,832 septic systems (Table 4.4). The number of septic systems was projected to increase to 2,159 by 2009.

Table 4.4 Estimated failing septic systems.

Impaired Segment	Septic Systems	Failing Septic Systems	Uncontrolled Discharges
London Bridge & Canal #2	77	17	3
Milldam Creek	51	13	5
Nawney Creek	260	40	4
West Neck Creek (Middle)	966	104	12
West Neck Creek (Upper)	478	51	2

4.3.2.1 Failing Septic Systems

Failing septic systems were assumed to deliver all effluent to the soil surface where it was available for wash-off during a runoff event. In accordance with estimates from Raymond B. Reneau, Jr. from Virginia Tech, a 40% failure rate for systems designed and installed prior to 1964, a 20% failure rate for systems designed and installed between 1964 and 1984, and a

5% failure rate on all systems designed and installed after 1984 was used in development of the TMDL for the Virginia Beach Coastal Area. Total septic systems in each category were calculated using U.S. Census Bureau block demographics. The applicable failure rate was multiplied by each total and summed to get the total failed septic systems per subwatershed. The fecal coliform density for septic system effluent was multiplied by the average design load for the septic systems in the subwatershed to determine the total load from each failing system. Additionally, the loads were distributed seasonally based on a survey of septic pump-out contractors to account for more frequent failures during wet months.

4.3.2.2 Uncontrolled Discharges

Uncontrolled discharges were estimated using 1990 U.S. Census Bureau block demographics. Houses listed in the Census sewage disposal category “other means” were assumed to be disposing sewage via uncontrolled discharges. Corresponding block data and subwatershed boundaries were intersected to determine an estimate of uncontrolled discharges in each subwatershed. Fecal coliform loads for each discharge were calculated based on the fecal density of human waste and the wasteload for the average size household in the subwatershed. The loadings from uncontrolled discharges were applied directly to the stream in the same manner that point sources are handled in the model.

4.3.2.3 Sewer System Overflows

During the model calibration period, (February 1998 to December 1998) there were 79 reported sewer overflows, none of these lead to a significant input of fecal bacteria into the watershed. While it may be assumed that additional occurrences of sewer overflows were likely undetected, a statistical analysis of meteorological events and sewer overflows was not able to be determined, so no projection of undetected sewer overflows was performed. The majority of sewer overflow event reports contained an estimate of the volume of sewage discharged, so the model included these discharges. The concentration of fecal bacteria discharged was considered to be equivalent to the concentration of septic tank effluent, and the magnitude of the discharge was estimated as the average discharge volume of reported sewer overflow events. As some biodegradation occurs in a septic system, it is felt that the estimate of concentration is conservative.

4.3.3 Livestock

Fecal coliform produced by livestock can enter surface waters through four pathways: land application of stored waste, deposition on land, direct deposition to streams, and diversion of wash-water and waste directly to streams. Each of these pathways is accounted for in the model. The number of fecal coliform directed through each pathway was calculated by multiplying the fecal coliform density with the amount of waste expected through that pathway. Livestock numbers determined for 2004 were used for the allocation runs, while these numbers were projected back to 2002 for the calibration runs. The numbers are based on data provided by VCE, DCR, NRCS, VBAA, VASS and FSA. For land-applied waste, the fecal coliform density measured from stored waste was used, while the density in as-excreted manure was used to calculate the load for deposition on land and to streams (Table 3.13). The use of fecal coliform densities measured in stored manure accounts for any die-off that occurs in storage. The modeling of fecal coliform entering the stream through diversion of wash-water was accounted for by the direct deposition of fecal matter to streams by cattle.

4.3.3.1 Land Application of Collected Manure

Significant collection of livestock manure occurs on various horse, and swine farms. For each farm in the drainage area, the average daily waste production per month was calculated using the number of animal units, weight of animal, and waste production rate as reported in Section 3.3.4. Swine were assumed to be in confinement 100% of the time with all waste stored in a lagoon. Stored waste was spread on pastured land. It was assumed that 100% of land-applied waste is available for transport in surface runoff unless the waste is incorporated in the soil by plowing during seedbed preparation. Percentage of cropland plowed and amount of waste incorporated was adjusted using calibration for the months of planting.

4.3.3.2 Deposition on Land

Horses were assumed to deposit all feces on pasture. The total amount of fecal matter deposited on the pasture landuse type was area-weighted.

4.3.4 Biosolids

Investigation of VDH data indicated that biosolids applications have occurred within the Virginia Beach Coastal Area. Detailed records of biosolids application location, timing and quantity were available, enabling the water quality modeling to be carried out in an "as applied" fashion, wherein the water quality model received land based inputs of biosolids loads on the day in which they actually occurred. During model calibration runs biosolids were modeled as having a fecal concentration of 375,000 cfu/g, the mean value of measured biosolid concentrations observed in samples from 30 sources applied during 1991 (VADEQ, 2003). Applications were modeled as being spread onto the land surface over a six hour period on the date of reported application, in the case of a multiple day application, loads were split evenly over the period reported. An assumption of proper application was made, wherein no biosolids were modeled as being spread in stream corridors. During this analysis, the water quality model predicted that in this study, biosolids application resulted in a negligible increase in instantaneous violations.

4.3.5 Wildlife

For each species of wildlife, a GIS habitat layer was developed based on the habitat descriptions that were obtained (Section 3.3.5). An example of one of these layers is shown in Figure 4.2. This layer was overlaid with the landuse layer and the resulting area was calculated for each landuse in each subwatershed. The number of animals per land segment was determined by multiplying the area by the population density. Fecal coliform loads for each land segment were calculated by multiplying the wasteload, fecal coliform densities, and number of animals for each species.

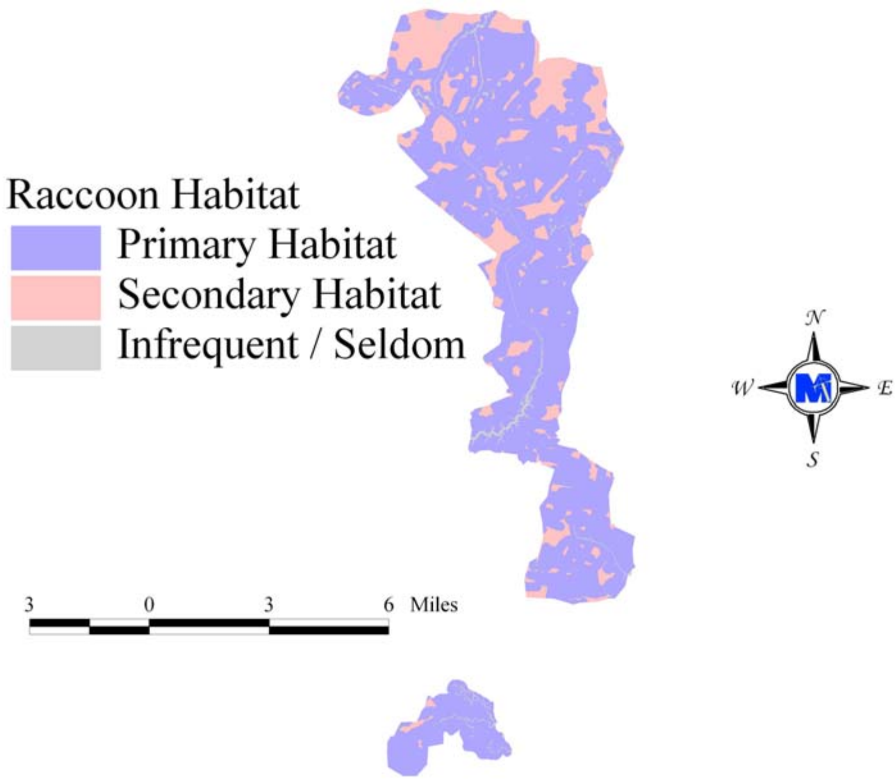


Figure 4.2 Example of raccoon habitat layer in the Virginia Beach Coastal Area, as developed by MapTech.

Seasonal distribution of waste was determined using seasonal food preferences for deer. Goose and duck wasteloads were varied based on migration patterns, but the load available for delivery to the stream was never reduced below 40% of the maximum to account for the resident population of birds. No seasonal variation was assumed for the remaining species. For each species, a portion of the total wasteload was considered land-based, with the remaining portion being directly deposited to streams. The portion being deposited to streams was based on the amount of time spent in stream access areas (Table 3.21). It was estimated that, for all animals other than beaver, 5% of fecal matter produced while in stream access areas was directly deposited to the stream. For beaver, it was estimated that 100% of fecal matter would be directly deposited to streams. No long-term (1995–2004) adjustments were made to wildlife populations, as there was no available data to support such adjustments.

4.3.6 Pets

Cats and dogs were the only pets considered in this analysis. Population density (animals per house), wasteload, and fecal coliform density are reported in Section 3.3.3. Waste from pets was distributed on residential landuses. The locations of households were taken from the 1990 and 2000 Census (USCB, 1990 and USCB, 2000). The landuse and household layers were overlaid, which resulted in number of households per landuse. The number of animals per landuse was determined by multiplying the number of households by the population density. The amount of fecal coliform deposited daily by pets in each landuse segment was calculated by multiplying the wasteload, fecal coliform density, and number of animals for both cats and dogs. The wasteload was assumed not to vary seasonally. The populations of cats and dogs were projected from 1990 data to 1995 and 2004.

4.4 Stream Characteristics

HSPF requires that each stream reach be represented by constant characteristics (*e.g.*, stream geometry and resistance to flow). In order to determine a representative stream profile for each stream reach, cross-sections were surveyed at some subwatershed outlets. One outlet was considered the beginning of the next reach, when appropriate. In the case of a confluence, sections were surveyed above the confluence for each tributary and below the confluence on the main stream.

Most of the sections exhibited distinct flood plains with pitch and resistance to flow significantly different from that of the main channel slopes. The streambed, channel banks, and flood plains were identified. Once identified, the streambed width and slopes of channel banks and flood plains were calculated using the survey data. A representative stream profile for each surveyed cross-section was developed and consisted of a trapezoidal channel with pitch breaks at the beginning of the flood plain (Figure 4.3). With this approach, the flood plain can be represented differently from the streambed. To represent the entire reach, profile data collected at each end of the reach were averaged.

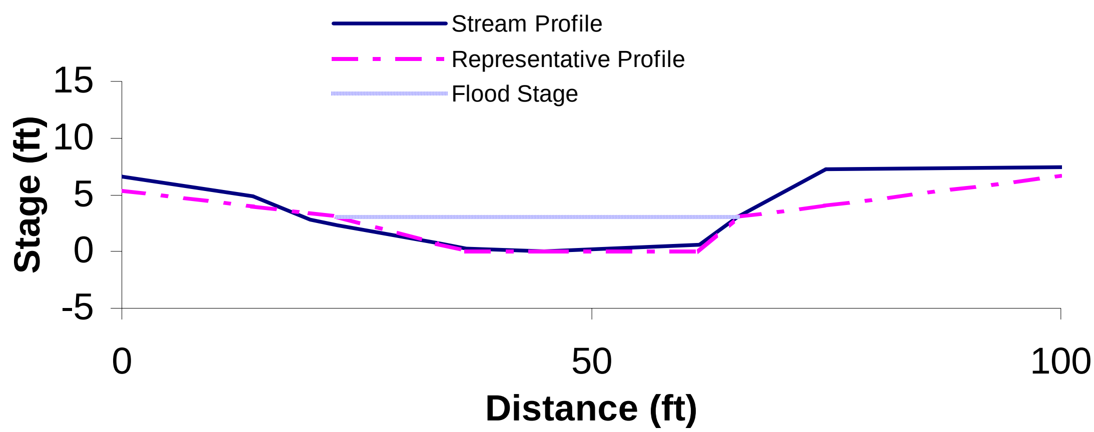


Figure 4.3 Stream profile representation in HSPF.

Conveyance was used to facilitate the calculation of discharge in the reach with different values for resistance to flow (Manning's *n*) assigned to the flood plains and streambeds. The conveyance was calculated for each of the two flood plains and the main channel; these figures were then added together to obtain a total conveyance. Calculation of conveyance was performed following the procedure described by Chow (1959). The total conveyance was then multiplied by the square root of the average reach slope to obtain the discharge (in ft^3/s) at a given depth.

A key parameter used in the calculation of conveyance is the Manning's roughness coefficient, *n*. There are many ways to estimate this parameter for a section. The method first introduced by Cowan (1956) and adopted by the Soil Conservation Service (1963) was used to estimate Manning's *n*. This procedure involves a 6-step process of evaluating the properties of the reach, explained in more detail by Chow (1959). Field data describing the channel bed, bank stability, vegetation, obstructions, and other pertinent parameters were collected. Photographs were also taken of the sections while in the field. Once the field data were collected, they were used to estimate the Manning's roughness for the section observed. The pictures were compared to pictures contained in Chow (1959) for validation of the estimates of the Manning's *n* for each section.

The result of the field inspections of the reach sections was a set of characteristic slopes (channel sides and field plains), bed widths, heights to flood plain, and Manning's roughness coefficients. Average reach slope and reach length were obtained from GIS layers of the watershed, which included elevation from Digital Elevation Models (DEMs) and a stream-flow network digitized from USGS 7.5-minute quadrangle maps (scale 1:24,000). These data were used to derive the Hydraulic Function Tables (F-tables) used by the HSPF model (Table 4.5). The F-tables developed consist of four columns: depth (ft), area (ac), volume (ac-ft), and outflow (ft^3/s). The depth represents the possible range of flow, with a maximum value beyond what would be expected for the reach. A maximum depth of 50 ft was used in the F-tables. The area listed is the surface area of the flow in acres. The volume corresponds to the total volume of the flow in the reach, and is reported in acre-feet. The outflow is simply the stream discharge, in cubic feet per second.

Table 4.5 Example of an "F-table" calculated for the HSPF model.

Depth (ft)	Area (ac)	Volume (ac-ft)	Outflow (ft^3/s)
0	0	0	0
0.1	0.6	1.69	0.05
0.17	10.76	4.46	24.26
0.77	10.76	10.44	241.7
7.67	11.84	82.36	11150.2
9.59	13.64	104.21	16167.77
11.99	35.37	186.7	21029.3
14.39	36.12	270.99	38599.01
246.99	108.79	16985.15	17519166
479.6	181.45	50601.57	76135368

4.5 Selection of Representative Modeling Period

Selection of the modeling period was based on two factors: availability of data (discharge and water-quality) and the need to represent critical hydrological conditions. The modeling period was selected to include the VADEQ assessment period from July 1990 through June 2001 that led to the inclusion of the impaired streams in this TMDL study area on the 1996, 1998, 2002 and 2004 Section 303(d) lists. The fecal concentration data from this period were evaluated to determine the relationship between concentration and the level of flow in the stream. High concentrations of fecal coliform were recorded in all flow regimes, thus it was concluded that the critical hydrological condition included a wide range of wet and dry seasons. The time period selected for hydrology calibration was 1/31/1998 to 6/30/1998.

For water quality calibration, data availability was the governing factor in the choice of calibration and allocation periods. Due to limited availability of data for running the hydrodynamic model, the water quality modeling period was restricted to February through December 1998, which coincided with 65 monitored points distributed over seven water quality monitoring stations.

4.6 Sensitivity Analysis

Sensitivity analyses are performed to determine a model's response to changes in certain parameters. This process involves changing a single parameter a certain percentage from a baseline value while holding all other parameters constant. This process is repeated for several parameters in order to gain a complete picture of the model's behavior. The information gained during sensitivity analysis can aid in model calibration, and it can also help to determine the potential effects of uncertainty in parameter estimation. Sensitivity analyses were conducted to assess the sensitivity of the model to changes in hydrologic and water quality parameters as well as to assess the impact of unknown variability in source allocation (*e.g.*, seasonal and spatial variability of waste production rates for wildlife, livestock, septic system failures, uncontrolled discharges, background loads, and point source loads). Additional analyses were performed to define the sensitivity of the modeled system to growth or technology changes that impact waste production rates.

4.6.1 Hydrology Sensitivity Analysis

The main hydraulic parameter in the CE-QUAL-W2 model, Manning's *n* was adjusted to -50%, -25%, -10%, 10%, 25%, and 50% of the base value. The results of this analysis indicate that changes in Manning's *n* are far out-weighed by the tidal input and wind speed, which are measured quantities, and the driving hydrologic force in these wind tidal tributaries.

4.7 Model Calibration Processes

Calibration is performed in order to ensure that the model accurately represents the hydrologic and water quality processes in the watershed. The model's hydrologic parameters were set based on available soils, landuse, and topographic data. Through calibration, these parameters were adjusted within appropriate ranges until the model performance was deemed acceptable.

4.7.1 Hydrology Calibration

In order to accurately represent a tidal estuary, the CE-QUAL-W2 model requires inputs of tidal height, wind, precipitation and runoff, preferably at an hourly interval or less. As the availability of these inputs is somewhat variable, model boundaries, and model time period needed to be set such that they would coincide with the best available data. The USGS has conducted two flow studies in the West Neck Creek to determine trends in flow as influenced by precipitation, tides and wind - one in 1993 and a second in 1998-1999. During the 1998 study, the following data were recorded: water surface elevation at Currituck Sound (15 min.), wind data at Oceana Naval Base (1 hour), and flow at West Neck Creek at Indian River Road in Pungo (15 min.). The tide and wind data from this study was used in the model, whereas the flow data at West Neck Creek was used to compare modeled output for assessing goodness of fit in calibration. In addition to the tidal data in Currituck Sound, two other boundary water surface elevation inputs were used: 8639348 Money Point, S. Br. Elizabeth River (1 hour interval), and Chesapeake Bay Bridge Tunnel, near the confluence of Lynnhaven and Chesapeake Bays (1 hour interval). Figure 4.4 shows a map of the modeled area, along with the gages used in this model. The model calibration period was chosen from 1/31/1998 to 6/30/1998 (150 days), a time when available wind data overlapped with monitored flow data.

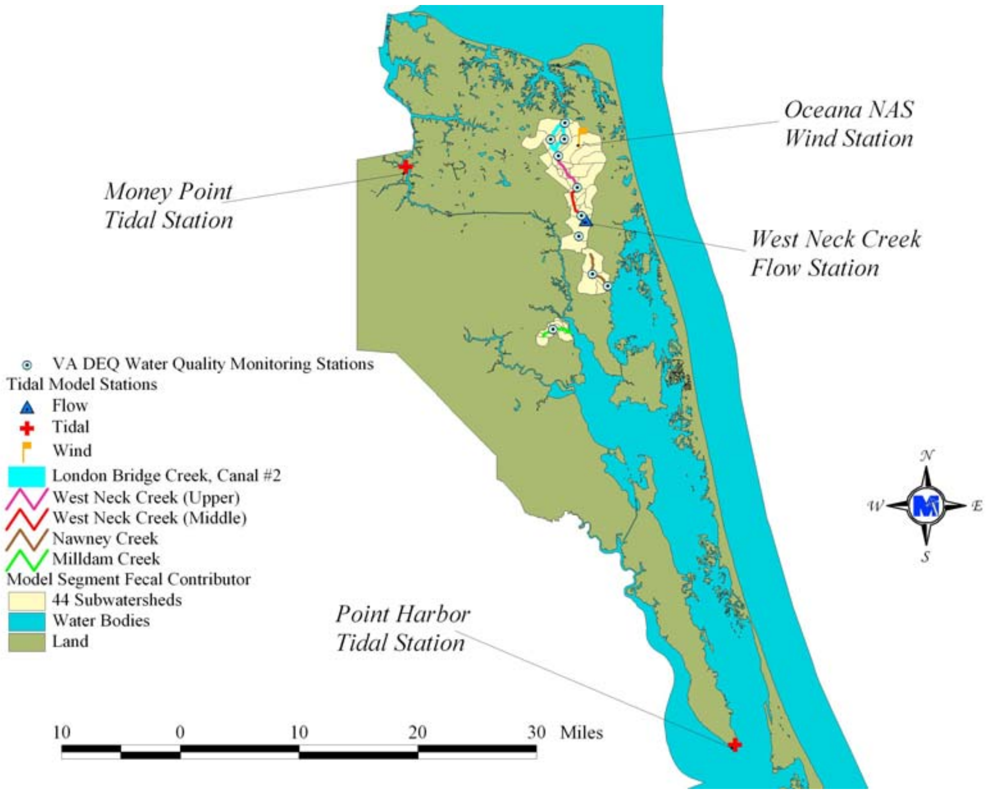


Figure 4.4 Subwatersheds delineated for modeling and location of VADEQ water quality monitoring stations and USGS Gaging Station in the Virginia Beach Coastal Area

4.7.2 Calibration - Wind/Tidal

The conclusion of the second USGS study was that wind was the primary factor in determining flow direction and magnitude in West Neck Creek, and that tides and precipitation (and, consequently, runoff) only augmented the direction of flow. Preliminary calibration runs support this conclusion. While using only tidal levels and precipitation as model driving factors, the model only correctly predicts net daily direction of flow 84.5% of the time, with an R-value = 0.53 (see Figure 4.5). When wind is added into the model, the percent correct rises to 94.1%, and the R-value = 0.84 (Figure 4.6). This is a strong correlation, particularly due to the fact that the model itself is fairly coarse outside of the study tributaries, and that the boundary conditions are separated by such a vast area.

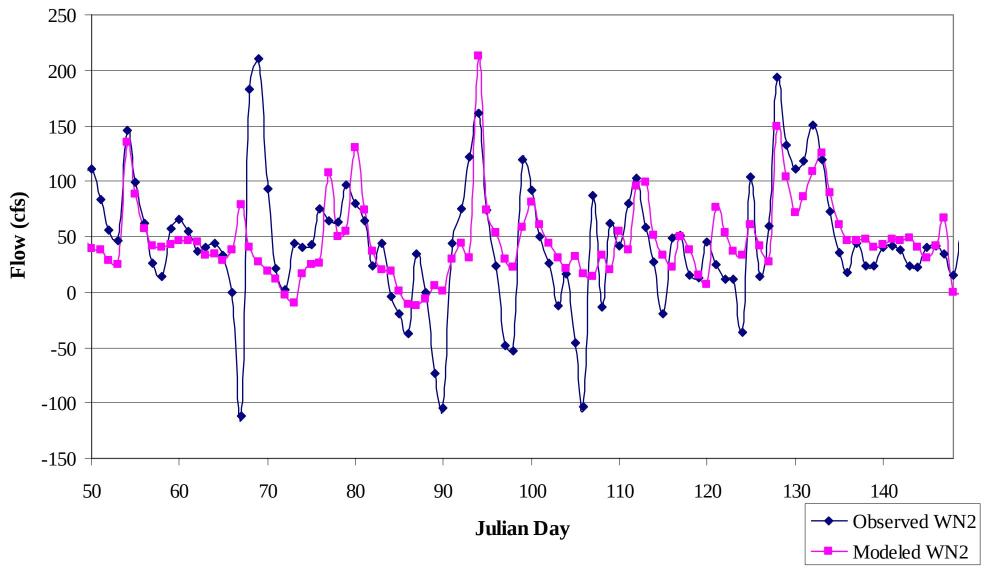


Figure 4.5 **Modeled versus observed flow for tidal model of Chesapeake and Albemarle Sound area, without considering the effects of wind. Observed flow was measured at USGS Gaging Station 02043200 West Neck Creek at Indian River Rd at Pungo, VA (WN2), from 1/31/1998 to 6/30/1998.**

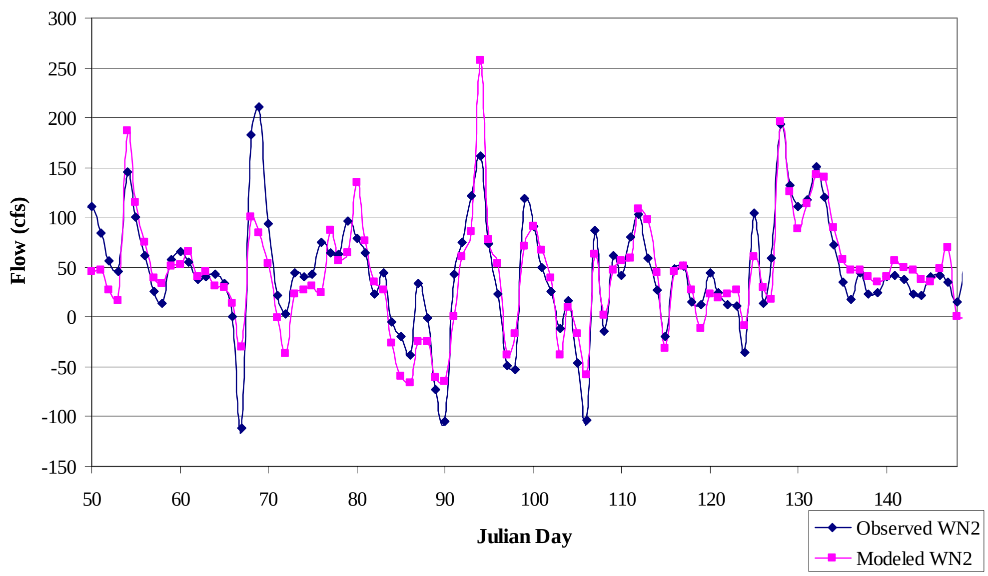


Figure 4.6 **Modeled versus observed flow for tidal model of Chesapeake and Albemarle Sound area, including the effects of wind. Observed flow was measured at USGS Gaging Station 02043200 West Neck Creek at Indian River Rd at Pungo, VA (WN2), from 1/31/1998 to 6/30/1998.**

Table 4.6 shows a comparison of observed versus modeled flow values for a variety of flow categories. The model performs well in all categories indicating model performance over a variety of circumstances.

There was no flow data in the other two impaired streams in this study, however, they are subject to influence by wind, and field visits during the development of this TMDL have indicated bi-directional flow in these streams as a consequence. In a wind tidal tributary, the most important characteristics will be channel geometry and orientation with respect to the wind, followed by the water surface height in the bounding water body and the surface characteristics governing runoff. The results of field surveys were used to determine the channel cross-sectional profile and aspect relative to the wind. The larger CE-QUAL-W2 model of the study area was used to predict surface height in the bounding water body, and a paired watershed approach was used to generate surface characteristics for hydrology. In this process, hydrology calibration parameter adjustments to base estimate values from soil and land use maps were taken from West Neck Creek and applied to the base estimates for Nawney, Milldam, and London Bridge Creeks as well as Canal #2.

Table 4.6 Results of hydrology calibration in tidal segment at USGS Gaging Station 02043200 West Neck Creek at Indian River Rd at Pungo, VA. Statistics are given for modeled versus observed flow from 2/1/1998 to 5/31/1998.

Criterion	Observed	Modeled	Error
Total flow (acre-ft)	11,553.87	11,627.32	0.64%
Net positive flow	10,198.19	10,234.64	0.36%
Net negative flow	-1355.68	-1392.68	2.73%
10% high flows	3479.92	3576.48	2.77%
50% low flows	2,663.26	3,067.81	15.19%
Mean positive flow	122.87	129.55	5.44%
Mean negative flow	-90.38	-73.30	-18.90%

4.7.3 Water Quality Sensitivity Analysis of Boundary Conditions

Given the results of the USGS study, suggesting that bi-directional flow was typical in West Neck Creek and the other wind tidal tributaries in this TMDL study, it is hypothesized that large bacteria concentrations in the water bodies adjoining these impaired streams may have significant influence on bacteria levels within the stream itself. In order to explore the impact of an elevated concentration in a boundary water body, a sample event with a boundary concentration of 1,000 cfu/100ml, and a fecal coliform die-off rate of 1.0/day was simulated for each impaired stream. Each event was chosen such that the elevated boundary concentration event lasted for 2 days, with the initial concentration of 0 cfu/100ml rising over 12 hours to a peak of 1,000 cfu/100 ml, maintained at that concentration for 24 hours, then falling over 12 hours back to a boundary level of 0 cfu/100 ml. The events were chosen such that they coincided with flow into the receiving stream from the bounding body. Table 4.7 shows the average flow rate during each study event, and the maximum concentration predicted in each receiving water body.

Table 4.7 Pollutant concentrations in receiving water body as a result of an event with a sustained 24-hour peak of 1,000 cfu/100ml in a bounding water body.

Receiving Body / Location	Originating Body	Flow at Peak (cfs)	Concentration (cfu/100ml)
Canal #2 @ 2.8 km	Lynnhaven/Broad Bay	118.00	1000.00
London Bridge @ 6.75 km	Lynnhaven/Broad Bay	118.00	539.80
Canal #2 (LB Creek) @ 1.2 km	Lynnhaven/Broad Bay	118.00	883.28
Canal #2 (LB Creek) @ 2.8 km	Lynnhaven/Broad Bay	118.00	511.50
London Bridge @ 9.25 km (confluence with Canal #2)	Lynnhaven/Broad Bay	118.00	416.46
West Neck Creek 6.25 km (@ Pungo)	Lynnhaven/Broad Bay	118.00	397.84
London Bridge @ 1.25 km	North Landing River	-71.00	421.74
London Bridge @ 6.75 km	North Landing River	-71.00	401.97
Canal #2 (LB Creek) @ 1.2 km	North Landing River	-71.00	526.14
Canal #2 (LB Creek) @ 2.8 km	North Landing River	-71.00	549.30
London Bridge @ 9.25 km (confluence with Canal #2)	North Landing River	-71.00	585.87
West Neck Creek 6.25 km (@ Pungo)	North Landing River	-71.00	678.72
Nawney Creek 0.0 km (@ NWN000.00)	Back Bay	-20.00	792.59
Nawney Creek 0.81 km	Back Bay	-8.50	275.72
Nawney Creek 1.5 km	Back Bay	-9.20	180.18
Nawney Creek 2.75 km (@ NWN001.84)	Back Bay	-32.50	15.79

Maximum movement of pollutant into London Bridge Creek, West Neck Creek and Canal #2 from Lynnhaven Bay will take place during positive flow event (flow is going from north to south), similarly, the maximum movement of pollutant from North Landing River will occur during a negative flow event (flow from south to north). To determine the potential influence of Lynnhaven Bay on water quality in these 3 streams, an event that produced an average daily flow of 118.0 cfs south at the West Neck Creek at Pungo gaging station was chosen.

The results indicate that the greatest impact from elevated concentrations in Lynnhaven Bay are seen in London Bridge Creek, and Canal #2, which had concentrations of 539.8 cfu/100 ml, and 883.0 cfu/100 ml respectively. West Neck Creek was also impacted, with a peak concentration of 397.84 cfu/100ml during this event. The effect of elevated concentrations in North Landing River was also significant. West Neck Creek had a predicted concentration of 678.72 cfu/100ml at Pungo, and concentrations of 421.74 cfu/100 ml in London Bridge Creek and 549.30 cfu/100 ml in Canal #2. These sample events, while contrived, are not necessarily unrealistic, given that the North Landing River at station 5BNLR013.61 had monitored fecal coliform concentrations in excess of 1,000 cfu/100 ml seven times between 4/1993 and 5/2004, with a peak value of 4,200 cfu/100 ml in 10/1995. Lynnhaven Bay, which has recently undergone a separate TMDL study, also has numerous monitored concentrations in excess of 1,000 cfu/100ml.

Nawney Creek is bounded at its downstream outlet by Back Bay, and flow is predicted to occur in both directions. A study of an event in Nawney Creek showed a maximum value of 750.2 cfu/100 ml. Mill Dam Creek showed a maximum concentration of 250.1 cfu/100 ml from a high bacteria event in North Landing River. The results of this analysis indicate that elevated levels of fecal coliform in either of the surrounding water bodies have the potential to cause water quality standard violations in these three impaired streams.

The results of this analysis indicate that elevated levels of fecal coliform in either of the surrounding water bodies have the potential to cause water quality standard violations in all five of these impaired streams. Given this situation, the choice of boundary conditions for concentrations in Lynnhaven Bay and North Landing River are of particular importance. The sparse nature of bacterial data makes this extremely challenging, with peak values and low values almost certainly missing from the record. In order to account for the general conditions, it was decided that a calendar year geometric mean value of observed bacteria levels in Lynnhaven Bay and North Landing River would be used for any day in which no data were present, while the actual bacteria value would be used for days in which there were data available. This resulted in a small window for extreme events, and a coarse estimate for all other days. The results of the sensitivity analysis (Table 4.7) suggest the impact that this will have on the model. Due to the predominantly (70-80%) southern flow direction, the most important boundary water body should be Lynnhaven Bay. Reaches subject to the greatest influence by Lynnhaven Bay (London Bridge Creek/Canal #2, Upper West Neck Creek) would have a narrow range of predicted water quality values, and consequently should be subject to fairly large errors on extreme highs or lows. As one moves farther from Lynnhaven Bay, this effect should decrease (Middle West Neck Creek). The results in Table 4.7 and Figures 4.7 through 4.14 support this hypothesis.

4.7.4 Water Quality Calibration

Water quality calibration is complicated by a number of factors, some of which are described here. First, water quality concentrations (*e.g.*, fecal coliform concentrations) are highly dependent on flow conditions. Any variability associated with the modeling of stream flow compounds the variability in modeling water quality parameters such as fecal coliform concentration. Second, the concentration of fecal coliform is particularly variable. Variability in location and timing of fecal deposition, variability in the density of fecal coliform bacteria in feces (among species and for an individual animal), environmental impacts on regrowth and die-off, and variability in delivery to the stream all lead to difficulty in measuring and modeling fecal coliform concentrations. Additionally, the maximum values were at times censored at 8,000 cfu/100ml and, at other times, at 16,000 cfu/100ml. Limited amount of measured data for use in calibration and the practice of censoring both high (over 24,000 cfu/100 ml) and low (under 100 cfu/100 ml) concentrations impede the calibration process.

Water quality calibration was conducted for the time period from 2/14/1998 through 12/31/1998. Four parameters were used for model adjustment. Three of the parameters (SQOLIM, WSQOP, and IOQC) were adjusted in the HSPF portion of the model. The fourth parameter, in-stream first-order decay rate (CG1DK), was adjusted in the CE-QUAL-W-2 model. The results of calibration are shown in Figures 4.7 through 4.14.

The hydrologic behavior of these areas was characterized by a high degree of interflow, and consequently low degree of direct runoff in these areas, it was necessary to simulate interflow concentrations of fecal coliform in order to match the observed recession curves of pollution plots. In addition to the relatively gradual recession of the falling arm of pollution plots, evidence of bacterial concentrations in shallow sub-surface flow has been detected (Rickmond Engineering, 2002). In order to reflect the variations in loading on land, and to provide for realistic mode response during reduction scenarios, the interflow concentration IOQC, was varied monthly, and was computed as a function of loading (MON-ACCUM).

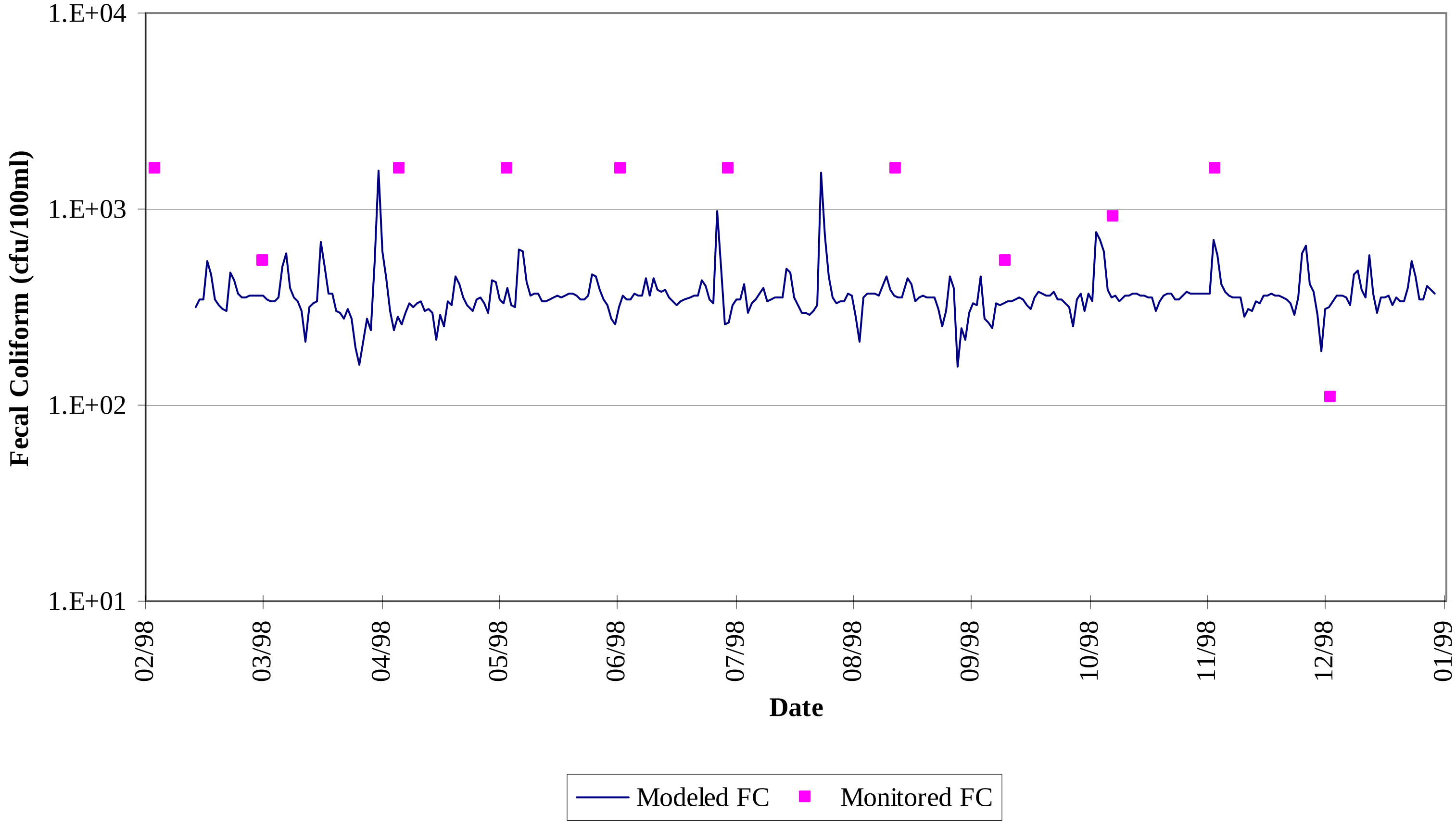


Figure 4.7 Quality calibration results for period 2/14/1998 to 12/31/1998 London Bridge Creek, model segment 7, subshed 2.

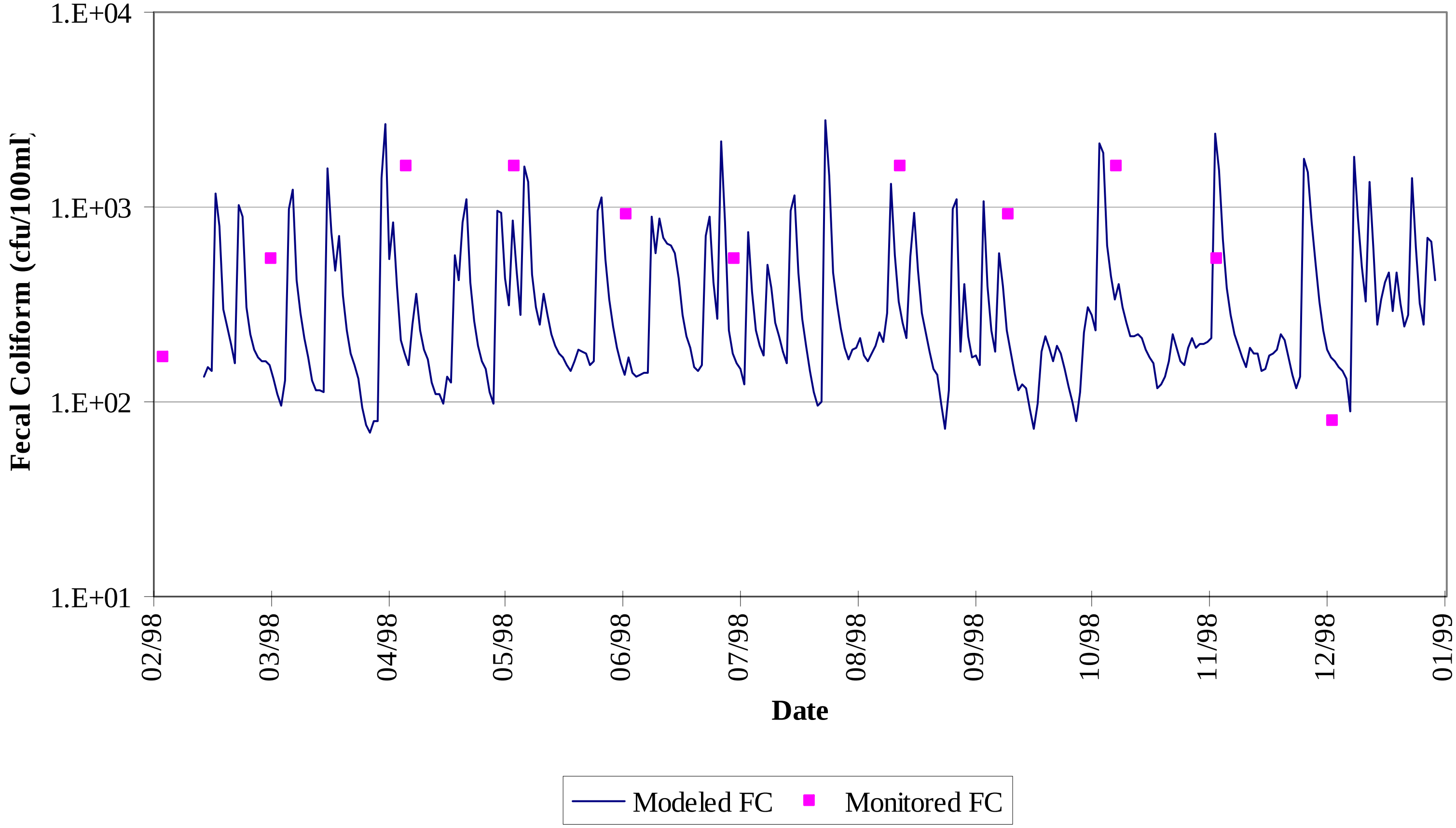


Figure 4.8 Quality calibration results for period 2/14/1998 to 12/31/1998 London Bridge Creek, model segment 7, subshed 6.

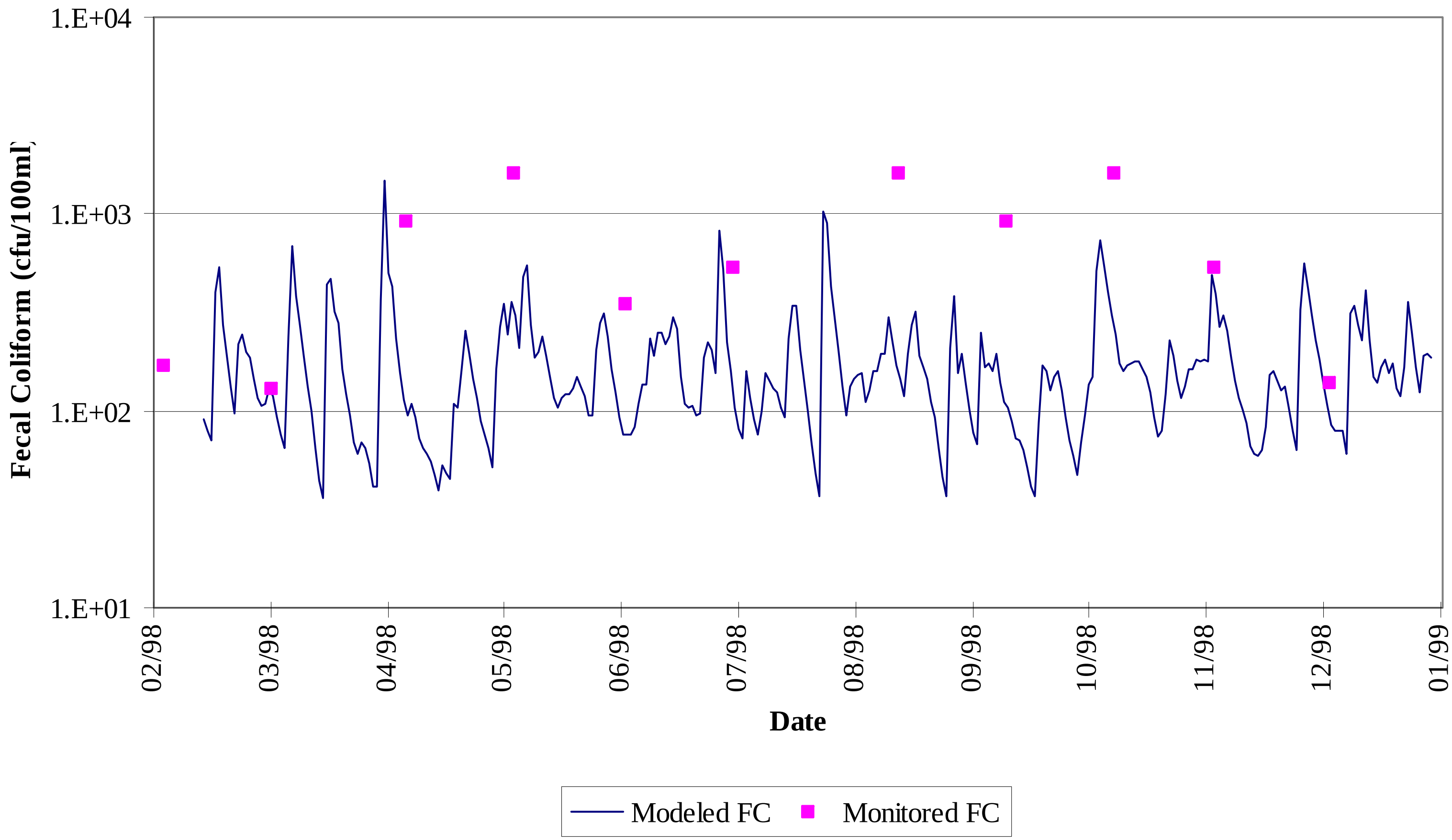


Figure 4.9 Quality calibration results for period 2/14/1998 to 12/31/1998 Canal #2, model segment 7, subshed 5.

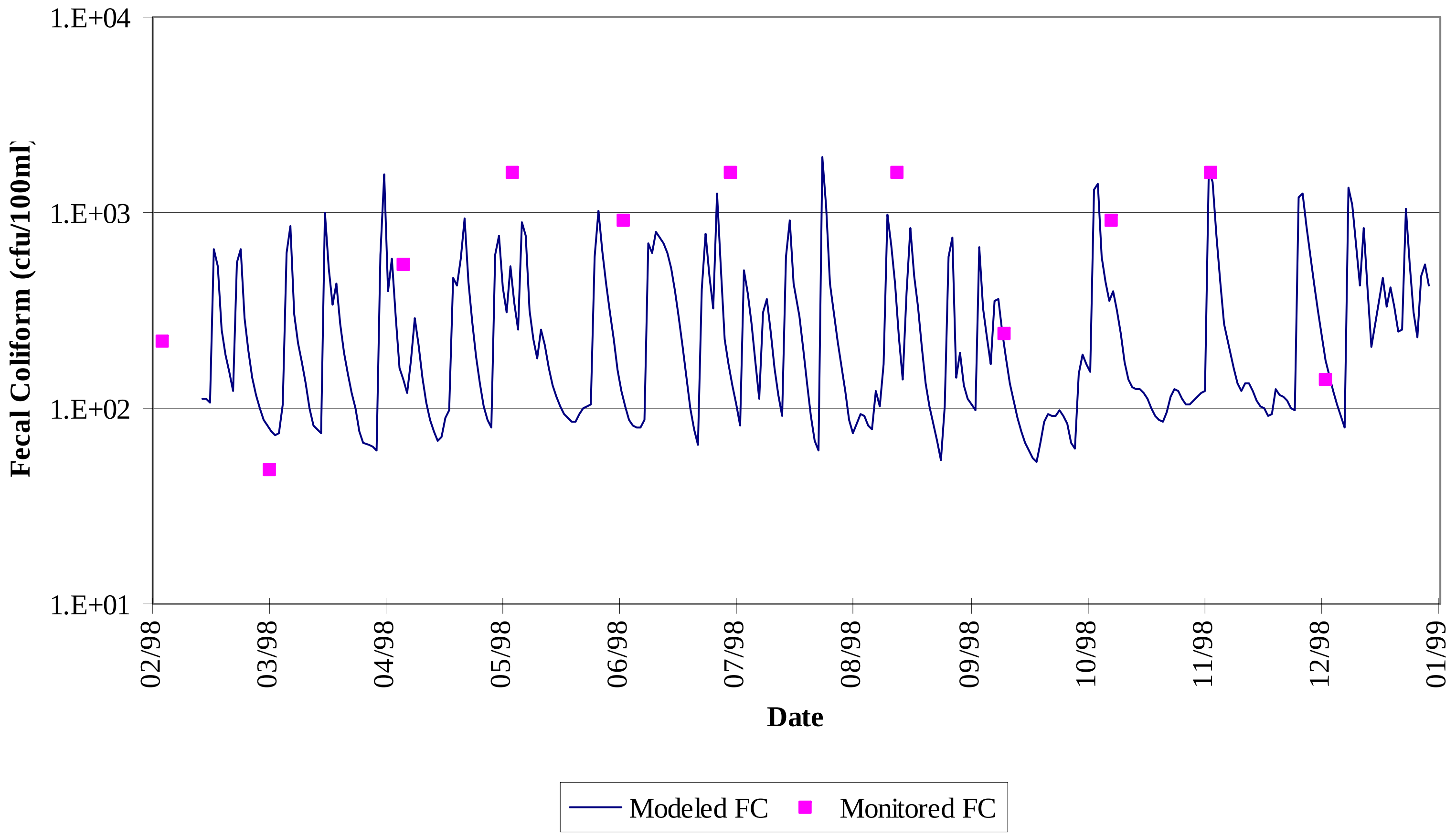


Figure 4.10 Quality calibration results for period 2/14/1998 to 12/31/1998 West Neck Creek (upper), model segment 7, subshed 11.

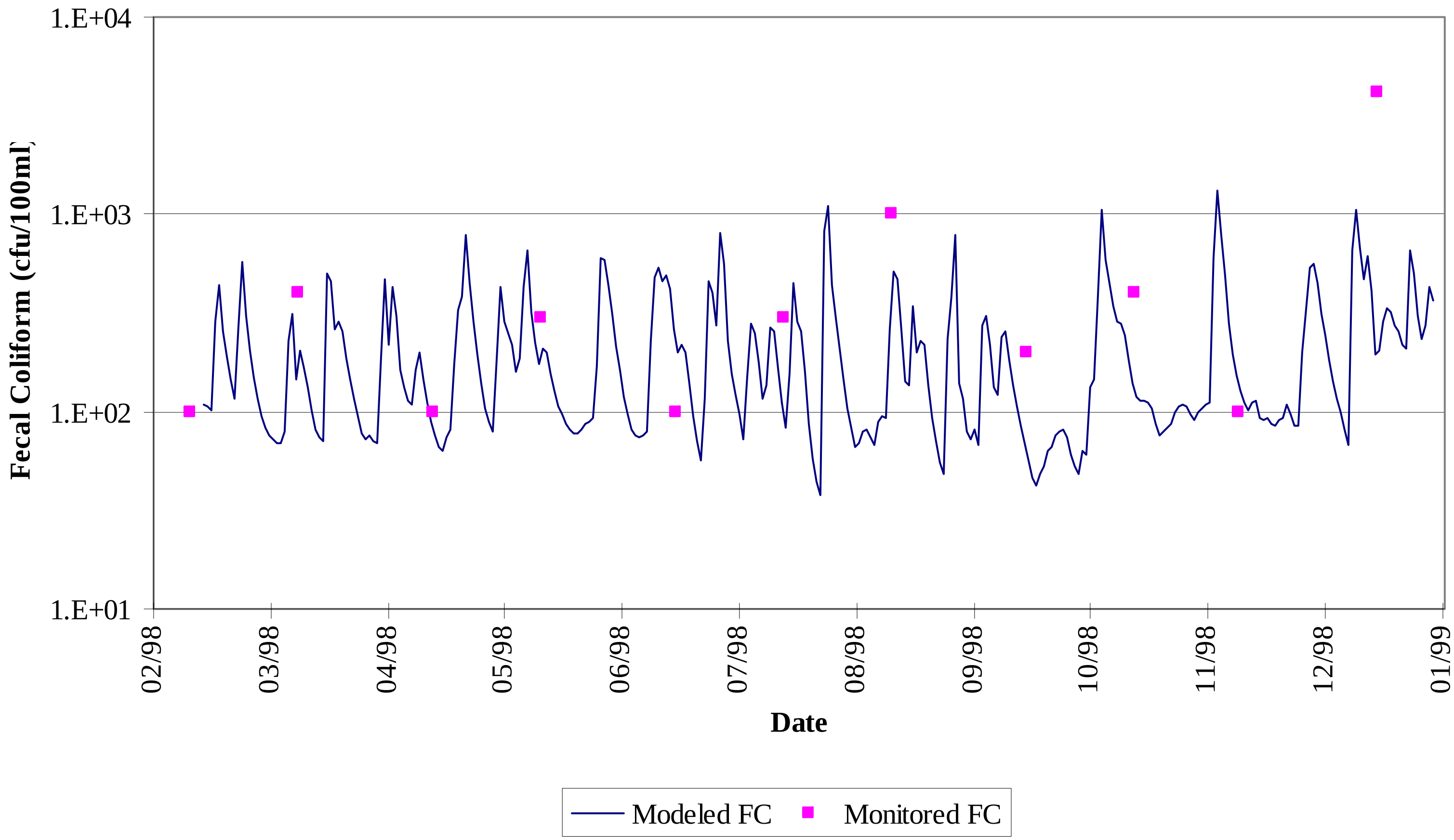


Figure 4.11 Quality calibration results for period 2/15/1998 to 12/31/1998 West Neck Creek (middle), model segment 7, subshed 25.

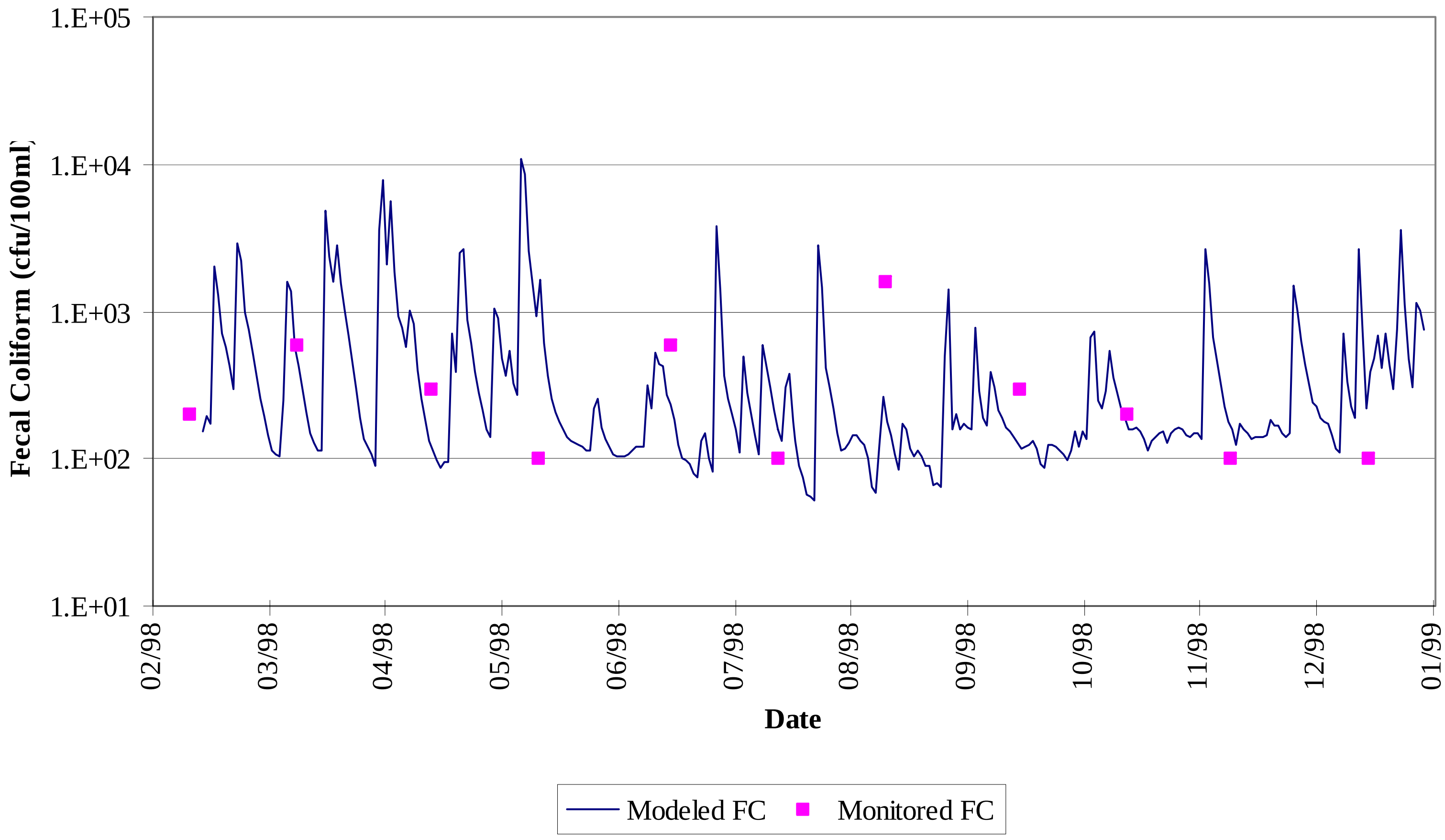


Figure 4.12 Quality calibration results for period 9/30/1998 to 12/31/1998 Nawney Creek, model segment 7, subshed 29.

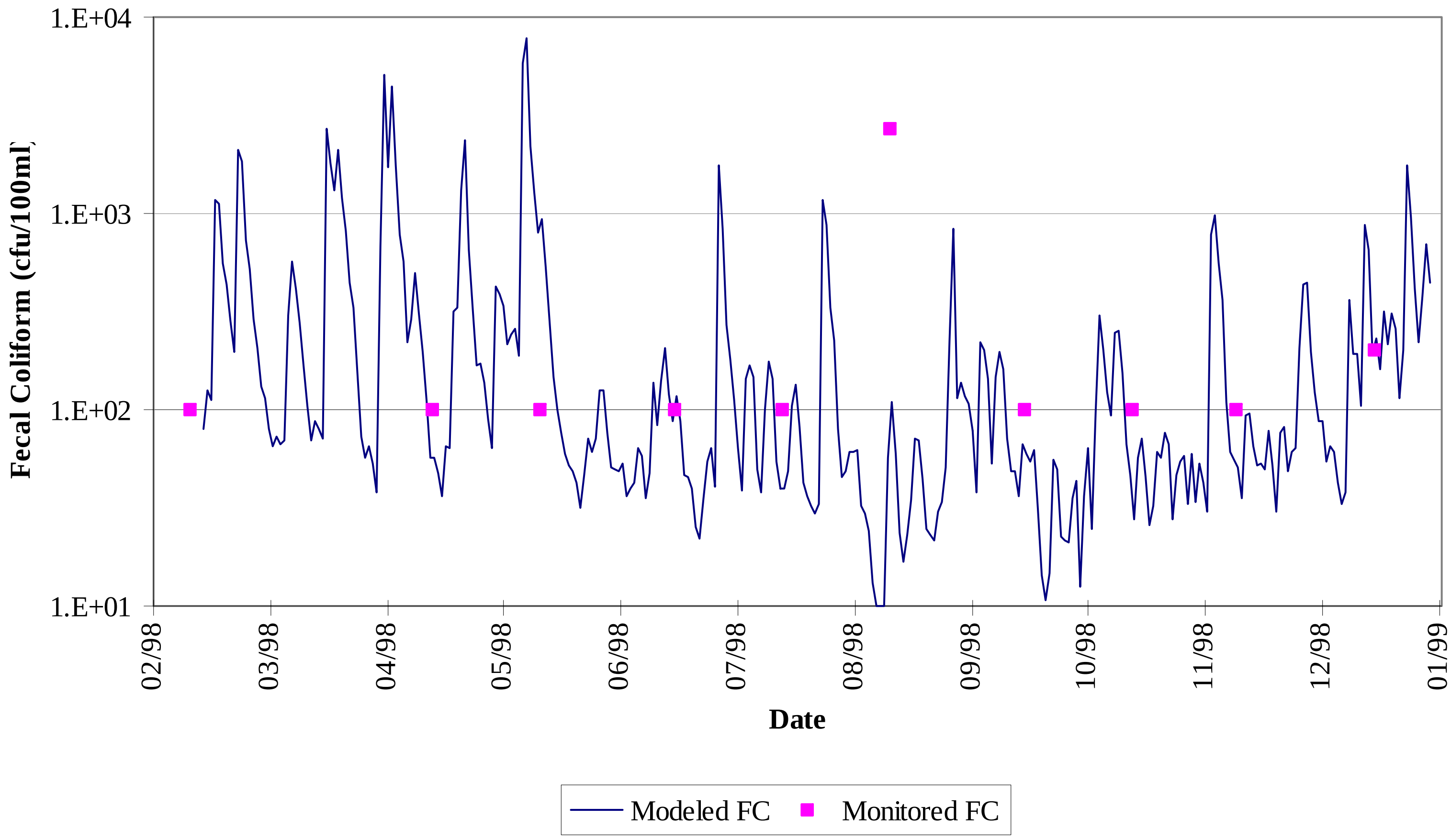


Figure 4.13 Quality calibration results for period 9/30/1998 to 12/31/1998 Nawney Creek, model segment 7, subshed 30.

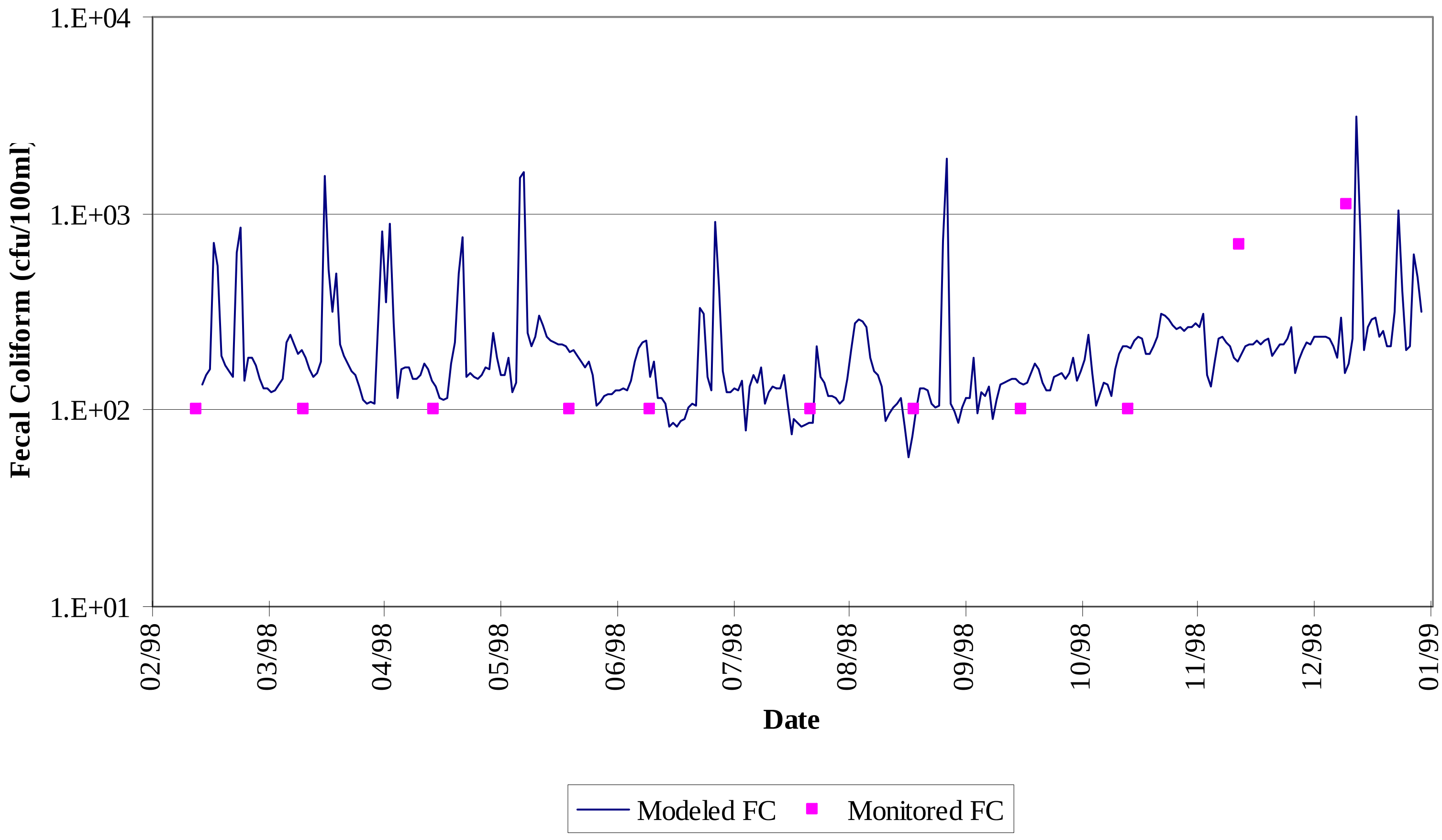


Figure 4.14 Quality calibration results for period 2/14/1998 to 12/31/1998 Milldam Creek, model segment 7, subshed 35.

Careful inspection of graphical comparisons between continuous simulation results and limited observed points was the primary tool used to guide the calibration process. To provide a quantitative measure of the agreement between modeled and measured data while taking the inherent variability of fecal coliform concentrations into account, each observed value was compared with modeled concentrations in a 2-day window surrounding the observed data point. Standard error in each observation window was calculated as follows:

$$Standard\ Error = \frac{\sqrt{\dfrac{\sum_{i=1}^{n}\left(observed - modeled_i\right)^2}{(n-1)}}}{\sqrt{n}}$$

where

$$\begin{aligned} observed &= \text{an observed value of fecal coliform} \\ modeled_i &= \text{a modeled value in the 2-day window surrounding the observation} \\ n &= \text{the number of modeled observations in the 2-day window} \end{aligned}$$

This is a non-traditional use of standard error, applied here to offer a quantitative measure of model accuracy. In this context, standard error measures the variability of the sample mean of the modeled values about an instantaneous observed value. The use of limited instantaneous observed values to evaluate continuous data introduces error and, therefore, increases standard error. The mean of all standard errors for each station analyzed was calculated. Additionally, the maximum concentration values observed in the simulated data were compared with maximum values obtained from uncensored data (Chapter 2) and found to be at reasonable levels.

Table 4.8 shows the predicted and observed values for instantaneous standard violation rate, and geometric mean for all impaired stream segments in the Virginia Beach Coastal Area. A least squares regression of observed versus modeled geometric means for stations with greater than 10 values (yielding 2 values per year), gives an R^2 of 0.72, a fairly strong relationship. This reflects that for the majority of stations with a substantial sample population, differences between both the violation rates and geometric means are well within the range of reasonable model error. In the cases of London Bridge Creek and Upper West

Neck Creek, however, the models predict substantially lower violation rates and geometric mean concentrations.

In London Bridge Creek/Canal #2 (modeled vs. observed of 17.9% vs. 87.1%, 6.88% vs. 42.86% and 27.19% vs. 44.9%) and Upper West Neck Creek (25.0% vs. 40.2%), the reasons for variability are related to the nature of the tidal system governing water quality in the area. The influence of Lynnhaven Bay on water quality in these streams has been shown to be of primary importance, particularly as one moves closer to Lynnhaven Bay (see Section 4.7.3). The key to modeling water quality in these bodies rests on choosing an appropriate boundary condition, as discussed in Section 4.7.3. London Bridge Creek/Canal #2 is the closest body of water to Lynnhaven Bay, and shows the greatest amount of error between modeled and observed bacterial levels. As the model moves from the southernmost reaches of London Bridge Creek into Upper West Neck Creek, the model, while still under-predicting violation rates, comes much closer to the observed violation rates (in Upper West Neck Creek modeled is 25.0% versus observed of 40.82%). As the model moves downstream to Middle West Neck Creek, it can be seen that the modeled violation rate closely matches the observed, 15.31% to 16.28%. Referring to Figures 4.7 through 4.11 for London Bridge Creek/Canal #2 and Upper West Neck Creek, it can be seen that modeled versus observed fecal coliform levels also follow this trend. Figure 4.7 shows the modeled versus observed bacterial levels in the London Bridge Creek northernmost reaches (closest to Lynnhaven Bay), which is obviously dominated by boundary bacteria levels in Lynnhaven Bay. As one moves toward Middle West Neck Creek the figures show progressively more variation in high and low values, and a better fit to observed data. The model performance in Middle West Neck Creek provides good evidence as to the model's validity, and its interconnectivity with Upper West Neck Creek, and London Bridge Creek/Canal #2, provides guidance as to the bacterial transport characteristics in these more difficult to model areas. Therefore, for model calibration, parameters affecting water quality were adjusted in London Bridge Creek/Canal #2 and Upper West Neck Creek in the same proportions as adjustments made in Middle West Neck Creek. As for the model allocation process, this source of model variability becomes less important, as upstream water quality standards compliance (*i.e.*, in Lynnhaven Bay) is assumed. This underscores the necessity of achieving water quality standards in Lynnhaven

Bay and North Landing River in order to achieve water quality standards in London Bridge Creek /Canal #2 and the West Neck Creeks.

Table 4.8 Comparison of modeled and observed geometric means.

Reach ID	Station ID	Modeled Calibration Load Fecal Coliform 2/14/98 -12/31/98			Monitored Fecal Coliform 2/14/98-12/31/98		
		***n*[1]**	**Geometric Mean (cfu/100ml)**	**Exceedances of Instantaneous Standard**	***n*[1]**	**Geometric Mean (cfu/100ml)**	**Exceedances of Instantaneous Standard**
2	7LOB003.70	321	358.53	17.9%	31	907.75	87.10%
5	7XBO001.30	321	146.18	6.88%	49	344.75	42.86%
6	7LOB001.79	321	269.19	27.19%	49	331.59	44.90%
11	5BWNC010.02	321	212.64	25.00%	49	299.69	40.82%
25	5BWNC003.65	321	161.50	15.31%	43	174.65	16.28%
29	5BNWN001.94	321	268.42	27.50%	44	220.43	25.00%
30	5BNWN000.00	321	175.49	16.56%	43	171.59	16.28%
35	5BMLD001.92	321	188.73	7.19%	49	163.35	16.33%

5. ALLOCATION

Total Maximum Daily Loads (TMDLs) consist of waste load allocations (WLAs, permitted sources) and load allocations (LAs, nonpoint sources) including natural background levels. Additionally, the TMDL must include a margin of safety (MOS) that either implicitly or explicitly accounts for the uncertainties in the process (*e.g*., accuracy of wildlife populations). The definition is typically denoted by the expression:

TMDL = WLAs + LAs + MOS

The TMDL becomes the amount of a pollutant that can be assimilated by the receiving waterbody and still achieve water quality standards. For fecal coliform bacteria, TMDL is expressed in terms of colony forming units (or resulting concentration). A sensitivity analysis was performed to determine the impact of uncertainties in input parameters.

5.1 Incorporation of a Margin of Safety

In order to account for uncertainty in modeled output, a MOS was incorporated into the TMDL development process. Individual errors in model inputs, such as data used for developing model parameters or data used for calibration, may affect the load allocations in a positive or a negative way. A margin of safety can be incorporated implicitly in the model through the use of conservative estimates of model parameters, or explicitly as an additional load reduction requirement. The intention of an MOS in the development of a fecal coliform TMDL is to ensure that the modeled loads do not underestimate the actual loadings that exist in the watershed. An implicit MOS was used in the development of this TMDL. By adopting an implicit MOS in estimating the loads in the watershed, it is ensured that the recommended reductions will in fact succeed in meeting the water quality standard. Examples of implicit MOS used in the development of this TMDL were:

- Allocating permitted point sources at the maximum allowable fecal coliform concentration,
- Selecting a modeling period that represented the critical hydrologic conditions in the watershed, and

- Modeling biosolids applications at the maximum allowable rate and fecal coliform concentration in all permitted fields.

5.2 Scenario Development

Allocation scenarios were modeled using a combination of HSPF and CE-QUAL-W2. Pollutant loadings under existing conditions were adjusted until the water quality standard was attained. The TMDLs developed for the Virginia Beach Coastal Area were based on the Virginia State Standard for *E. coli* and *enterococci*. As detailed in Section 2.1, the *E. coli* standard states that the calendar month geometric-mean concentration shall not exceed 126 cfu/100 ml, and that a maximum single sample concentration of *E. coli* shall not exceed 235 cfu/100 ml. The *enterococci* standard states that the calendar month geometric-mean concentration shall not exceed 35 cfu/100 ml, and that a maximum single sample concentration of *enterococci* shall not exceed 104 cfu/100 ml. According to the guidelines put forth by the VADEQ (VADEQ, 2003) for modeling *E. coli* with HSPF, the model was set up to estimate loads of fecal coliform, then the model output was converted to concentrations of *E. coli* through the use of the following equation (developed from a data set containing n-493 paired data points):

$$\log_2(C_{ec}) = -0.0172 + 0.91905 \cdot \log_2(C_{fc})$$

where C_{ec} is the concentration of *E. coli* in cfu/100 ml, and C_{fc} is the concentration of fecal coliform in cfu/100 ml. Per the guidelines put forth by the VADEQ (VADEQ, 2004) for modeling *enterococci* with HSPF and CE-QUAL-W2, the model was set up to estimate loads of fecal coliform, then the model output was converted to concentrations of e*nterococci* through the use of the following equation (developed from a data set containing 800+ paired data points):

$$\log_2(C_{ent}) = 1.2375 + 0.59984 \cdot \log_2(C_{fc})$$

where C_{ent} is the concentration of *enterococci* in cfu/100 ml, and C_{fc} is the concentration of fecal coliform in cfu/100 ml.

Pollutant concentrations were modeled over the entire duration of a representative modeling period, and pollutant loads were adjusted until the standard was met (Figures 5.1 through 5.10). The development of the allocation scenario was an iterative process that required numerous runs with each followed by an assessment of source reduction against the water quality target.

5.2.1 Wasteload Allocations

Within the Virginia Beach Coastal Area there are two Municipal Separate Storm Sewer System (MS4) permits requiring TMDL allocations. Table 5.1 lists the permittee and receiving streams for these MS4 discharges. In allocating their TMDL, loads were based on each permittee's share of the contributing area of the impairment. The load for each MS4 permit was modeled as the load from impervious surfaces within the boundaries of the area covered by the MS4 (*e.g.*, NAS Oceana) falling within the impairment drainage area. Reductions to existing NPS loads were applied to all affected land areas, regardless of the existence of an MS4 permit.

Table 5.1 Regulated storm water discharges in the Virginia Beach Coastal Area.

Municipality	Receiving Stream
Virginia Beach – VA0088676	West Neck Creek London Bridge Creek
US Naval Station Oceana – VAR040043	West Neck Creek London Bridge Creek Wolfsnare Creek Great Neck Creek Redwing Lake

5.2.2 Load Allocations

Load allocations to nonpoint sources are divided into land-based loadings from landuses and directly applied loads in the stream (*e.g.*, livestock, sewer overflows, and wildlife). Source reductions include those that are affected by both high and low flow conditions. Land-based NPS loads had their most significant impact during high-flow conditions, while direct deposition NPS had their most significant impact on low flow concentrations. The BST results for 2003-2004 confirmed the presence of human, livestock, pet, and wildlife contamination. Load reductions were performed by landuse, as opposed to reducing sources, as it is considered that the majority of BMPs will be implemented by landuse. Reductions on land uses address all sources of fecal bacteria contributing to that landuse. For instance, reductions on agricultural landuses (pasture and cropland) include, but are not limited to, reductions required for biosolids and imported poultry litter.

Allocation scenarios were run sequentially, beginning with headwater impairments, and then continuing with downstream impairments until all impairments were allocated to 0% exceedances of the instantaneous standard. Tables 5.2 through 5.6 represent a small portion of the scenarios developed to determine the TMDL for each impairment. Scenario 1 in each table describes a baseline scenario that corresponds to the existing conditions in the watershed. Model results indicate that human, livestock, and wildlife contributions are significant in all areas of the watershed. This is in agreement with the results of BST analysis presented in section 2.4.2.1.

Reduction scenarios exploring the role of anthropogenic sources in standards violations were explored first to determine the feasibility of meeting standards without wildlife reductions. In each table, scenario 2 attempts to determine the impact of non-anthropogenic sources (*i.e.,* wildlife), by exploring 100% reductions in all anthropogenic land-based and direct loads. In most cases, the model predicts that water quality standards will not be met without reductions in wildlife loads.

Since part of the TMDL development is the identification of phased implementation strategies, typical management scenarios were explored as well. Scenario 3 in each table contains reductions of 50% in all anthropogenic land-based loads, 100% reduction in sewer overflows and uncontrolled residential discharges, a 90% or 100% reduction in direct livestock deposition, and a 0% reduction in wildlife direct and land-based loading to the stream. This scenario corresponds to what is considered to be a reasonable scenario for a stage I implementation. Further scenarios in each table explore a range of management scenarios, leading to the final allocation scenario that contains the predicted reductions needed to meet the water quality standard of 0% instantaneous violations.

5.2.2.1 London Bridge Creek & Canal #2

London Bridge Creek is located in the north central portion of the Virginia Beach City limits and is considered an estuary that generally flows in a northerly direction. London Bridge Creek is in the Chesapeake Bay/Atlantic Small Coastal River Basin. The impaired section begins at the Bow Creek Blvd. Bridge and ends at the Thurston Branch confluence (0.11 square miles). The watershed is 41% residential 15% commercial and 11% forested.

Total fecal coliform production per year in the watershed was modeled as 95.65E+13. Major sources of fecal coliform include dogs (71%), raccoon (9%) and sea gulls (9%). The total wildlife contribution to the fecal coliform load is 23%. In addition to these non-point sources (NPS), sewer overflows in the London Bridge and Canal #2 drainage areas occurred at a reported rate of approximately 7 per year in the period 1998-2003. The long term VADEQ monitoring stations, 7-LOB001.79, 7-LOB00003.70 and 7-XBO001.30, have historical fecal coliform violation rates of 56%, 88% and 41%, respectively. Since the TMDL endpoint for London Bridge Creek is in terms of *enterococci*, VADEQ developed a draft fecal coliform to *enterococci* translator for use in this study (see Section 5.2 regarding the use and development of this translator).

London Bridge Creek and Canal #2 share hydrologic connectivity with Lynnhaven Bay to the north, and the results of the tidal water quality model indicate that the water quality in London Bridge Creek and Canal #2 is greatly influenced by water quality in Lynnhaven Bay (see Section 4.74). Therefore, the boundary concentration chosen for the tidal model has a great impact on the water quality in London Bridge Creek and Canal #2. In order to avoid inducing geometric mean standard violation in London Bridge Creek due to elevated boundary concentrations, it was assumed that the average daily fecal coliform concentration in Lynnhaven Bay is 89 cfu/100 ml, which translates to 35 cfu/100 ml *enterococci*, the geometric mean standard. It is understood that water quality levels will fluctuate during the course of the year, and that historical levels of bacteria in Lynnhaven Bay have been considerably higher than this boundary condition, however, this conservative assumption is necessary to determine the local contribution to water quality from the land area draining directly into these water bodies.

Scenario 1 shows the predicted violation rate of the *enterococci* standard under existing conditions to be 19.38%. Scenario 2 shows that reducing 100% of the anthropogenic load will result in the achievement of water quality standards, due to the predominance of human related sources in this watershed. Scenario 3 predicts that a 50% decrease from agricultural and urban NPS will result in a 9.06% exceedance of the single sample standard, however the geometric mean bacteria levels are predicted to still exceed the standard 100% of the time. Scenario 6 shows the predicted decreases necessary to achieve a 0% exceedance of the instantaneous and geometric mean standards.

Table 5.2 Allocation scenarios for bacterial concentration with current loading estimates in model segment 7 London Bridge Creek & Canal #2.

Scenario Number	Percent Reduction in Loading from Existing Conditions					Percent Violations	
	Direct Wildlife	NPS Forest / Wetland	NPS Pasture / Livestock Access / Crops	Straight Pipe / Sewer Overflow	NPS Res. / Urban	GM > 35 cfu/100ml	Single Sample > 104 cfu / 100ml
1	0	0	0	0	0	100	19.38
2	0	0	100	100	100	0.00	0.00
3	0	0	50	100	50	100	9.06
4	0	0	80	100	80	8.33	0.94
5	0	0	85	100	85	8.33	0.31
6	0	0	88	100	88	0.00	0.00

5.2.2.2 Milldam Creek

Milldam Creek is located in the southern portion of the Virginia Beach City limits and generally flows in an easterly direction. The impaired segment begins at the headwaters and ends 3.29 miles downstream. It is considered to be a wind tidal tributary, and thus experiences bi-directional flow. Its TMDL endpoint is for *E. coli*. It is also connected via an un-named tributary to the Blackwater River, and so has the potential to receive pollutants from outside of its direct contributing area under certain circumstances. The watershed is 61% wetlands with 26% in cropland.

Total fecal coliform production per year in the watershed was modeled as 15.95E+13. Major sources of fecal coliform bacteria include sea gull (28%) and raccoon (22%), with approximately 8% of the annual load coming from un-controlled residential discharges and failing septic systems. The total wildlife contribution to the fecal coliform load was estimated at 88%. The long term VADEQ monitoring station, 5BMLD001.92, has a historical fecal coliform violation rate of 17%. The rate of fecal coliform violations during TMDL development was 17% as well, however, there were 0% violations of the *E. coli* standard during this same time period.

Scenario 1 predicts an *E. coli* instantaneous standard violation rate of 7.19% for existing conditions. Scenario 2 suggests that there will still be a violation rate of 4.38% with the elimination of all bacteria from agricultural and residential landuses. It is important to note that these reductions are done by landuse, not by source, as it is considered that a management practice affecting pollutant transport will affect all sources that deposit on a given landuse. Since the water quality model takes wildlife deposition on residential and agricultural landuses into account. Scenarios 3 through 7 explore increasing reductions, leading to a 0% exceedance of both standards.

Table 5.3 Allocation scenarios for bacterial concentration with current loading estimates in model segment 7, Milldam Creek.

Scenario Number	Percent Reduction in Loading from Existing Conditions						Percent Violations	
	Direct Wildlife	NPS Forest / Wetland	Direct Livestock	NPS Pasture / Livestock Access / Crops	Straight Pipe / Sewer Overflow	NPS Res. / Urban	GM > 126 cfu/100ml	Single Sample > 235 cfu / 100ml
1	0	0	0	0	0	0	75.00	12.19
2	0	0	100	100	100	100	0.00	4.38
3	0	0	100	50	100	50	8.33	5.31
4	0	10	100	99	100	99	0.00	3.75
5	0	65	100	99	100	99	0.00	1.25
6	0	83	100	99	100	99	0.00	0.31
7	0	91	100	99	100	99	0.00	0.00

5.2.2.3 Nawney Creek

Nawney Creek is located in the southeastern portion of the Virginia Beach City limits and is considered an estuary that generally flows in an eastern direction, but is influenced by wind effects and exhibits some bi-directional flow. The impaired segment begins 0.8 miles upstream from the Nawney Road crossing and ends 0.92 miles downstream from the Nawney Road crossing (0.52 square miles). Since Nawney Creek is considered an estuary, its TMDL end-point is based on the *enterococci* standard, and therefore the impairment is modeled as fecal coliform, then the output of the model is converted to *enterococci* using the VADEQ translator. This generally results in significantly lower instantaneous violation rates for *enterococci* than for fecal coliform, but higher rates for violations of the geometric mean standard. The watershed is 51% cropland, 22% wetlands and 15% pasture.

Total fecal coliform production per year in the watershed was modeled as 24.81E+14 during model calibration, however, during allocation it was modeled at 73.03E+13, due to a substantial decrease in the number of hogs in the watershed (from 2,727 prior to 2001 to 500 present day). Presently the major sources of fecal coliform in the watershed are hogs (41%), waterfowl (15%) and raccoon (12%). Failing septic systems and untreated residential discharges are expected to contribute as much as 3% of the total annual load of fecal coliform. The total wildlife contribution to the fecal coliform load is 32%. The long term VADEQ monitoring stations, 5BNWN001.84 AND 5BNW000.00, had violation rates of 23.1% and 14.1% during the most recent assessment period. During the model calibration period, the monitored fecal coliform violation rate was 25.0% at 5BNWN001.84 and 16.3% at 5BNWN000.00, as compared to the modeled violation rates of 27.5% and 16.6%.

With the current populations, the predicted violation rate of the *enterococci* standard is 6.88% instantaneous, and 100% geometric mean. Scenario 2 predicts that with a 100% reduction in all anthropogenic sources (residential and agricultural), no violations of the instantaneous standard will occur, thus necessitating no wildlife reductions in order to achieve 0% exceedances. Scenarios 3 & 4 show sample management scenarios, whereby 100% of uncontrolled residential discharges are eliminated, and NPS urban and agricultural loads are reduced by 15% and 50% respectively. Scenario 4 results in predicted violation rates of 2.44% instantaneous, and 16.66% geometric mean. Scenarios 5 and 6 represent increasingly stringent human and wildlife reductions culminating in a 0% exceedance rate of both standards.

Table 5.4 Allocation scenarios for bacterial concentration with current loading estimates in model segment 7, Nawney Creek.

Scenario Number	Percent Reduction in Loading from Existing Conditions					Percent Violations	
	Direct Wildlife	NPS Forest / Wetland	NPS Pasture / Livestock Access / Crops	Straight Pipe / Sewer Overflow	NPS Res. / Urban	GM > 35 cfu/100ml	Single Sample > 104 cfu / 100ml
1	0	0	0	0	0	100.00	6.88
2	0	0	100	100	100	0.00	0.00
3	0	0	15	100	15	33.00	5.00
4	0	0	50	100	50	16.66	3.44
5	0	0	80	100	80	0.00	1.31
6	0	0	85	100	85	0.00	0.00

5.2.2.4 West Neck Creek (Middle)

The middle portion of West Neck Creek is located in the north central portion of the Virginia Beach City limits and at this location West Neck Creek is considered a free flowing stream flowing in a southerly direction. However, Middle West Neck Creek shares hydrologic connectivity with Upper West Neck Creek (and consequently with London Bridge Creek and Lynnhaven Bay), and flow monitoring studies have shown that flow is northward approximately 25 to 35% of the time (under these circumstances Middle West Neck Creek will actually receive flow from North Landing River). During the remaining portion of the year (65 to 75% of the time) the flow is in a southward direction. Because of this tidal connection, much of the flow through this portion of West Neck Creek originates outside of the direct contributing area of Middle West Neck Creek. As a result, water quality in its boundary waters has a significant impact (as described in greater detail in Section 4.7.4). The TMDL endpoint for West Neck Creek is *E. coli*, not *enterococci*. Allocations in West Neck Creek were performed with its boundary conditions in North Landing River set at the geometric mean of monitored values in North Landing River (which is well below the geometric mean standard) and with Upper West Neck Creek having no violations of the instantaneous and geometric mean standards for *E. coli*. The impaired segment begins at the Princess Anne Road Crossing and ends 0.55 miles below the Indian River crossing (3.1 stream miles). The watershed is 45% cropland, 33% wetlands and 3% forested.

Total fecal coliform production per year in the watershed was modeled as 30.80E+13. Major sources of fecal coliform bacteria in this watershed are waterfowl (27%), raccoon (22%), dogs (15.5%) and muskrat (9%). The total wildlife contribution to the fecal coliform load is approximately 60%. The long term VADEQ monitoring station, 5BWNC003.65, had a fecal coliform violation rate of 16.3% during the modeling period.

Scenario 1 shows the modeled geometric mean and instantaneous violation rates under existing conditions to be 25% and 15.63% respectively, with existing conditions in its boundary waters. Scenario 2 predicts that with the elimination of all anthropogenic sources in Middle West Neck Creek and its boundary waters no instantaneous or geometric mean violations will occur. Scenario 3 predicts that with a reduction of 50% of the anthropogenic load, 0% violations of the geometric mean standard will occur, and 4.69% violations of the instantaneous standard. Scenarios 4 through 6 show the models predictions for reductions that are required to reach 0% violation rate for both standards.

Table 5.5 Allocation scenarios for bacterial concentration with current loading estimates in model segment 7, West Neck Creek (Middle).

Scenario Number	Percent Reduction in Loading from Existing Conditions					Percent Violations	
	Direct Wildlife	NPS Forest / Wetland	NPS Pasture / Livestock Access / Crops	Straight Pipe / Sewer Overflow	NPS Res. / Urban	GM > 126 cfu/100ml	Single Sample > 235 cfu / 100ml
1	0	0	0	0	0	25.00	15.63
2	0	0	100	100	100	0.00	0.00
3	0	0	50	100	50	0.00	4.69
4	0	0	80	100	80	0.00	0.31
5	0	0	82	100	82	0.00	0.31
6	0	0	84	100	84	0.00	0.00

5.2.2.5 West Neck Creek (Upper)

The upper portion of West Neck Creek is located in the north central portion of the Virginia Beach City limits and this portion of West Neck Creek is considered an estuary that flows in a northerly direction, with a TMDL endpoint expressed in terms of *enterococci*. The upper part of West Neck Creek is included in the Chesapeake

Bay/Atlantic Small Coastal River Basin. The impaired segment begins at the Princess Anne road crossing and ends at the London Bridge Creek confluence (0.03 square miles). While West Neck Creek is considered part of the Chesapeake Bay/Atlantic Small Coastal River Basins, a flow study at its southernmost reaches in 1990-1991 concluded that approximately 65% of the average daily flow went southward into Middle West Neck Creek and North Landing River, thus receiving flow from London Bridge Creek and Canal #2. This is a fairly complicated set of flow conditions, resulting in a situation where water quality in Upper West Neck Creek is heavily dependent upon the water quality in its surrounding water bodies. Allocations in West Neck Creek were performed in concert with its bounding streams, Middle West Neck Creek and London Bridge Creek and Canal #2, allocated to 0% violations of the instantaneous and geometric mean standards. The watershed is 30% residential, 22% wetlands and 15% cropland.

Total fecal coliform production per year in the watershed was modeled as 10.89E+14. Major sources of fecal coliform bacteria in this watershed are dogs (37%), waterfowl (20%), raccoon (19%) and horses (10%). The total wildlife contribution to the fecal coliform load is 44%. The long term VADEQ monitoring station, 5BWNC010.02, has a historical fecal coliform violation rate of 40.82% during the modeling period. *enterococci* data has been collected in West Neck Creek only during TMDL development.

Scenario 1 shows the existing conditions as predicted by the water quality model in Upper West Neck Creek. Scenario 2 predicts that with the elimination of all anthropogenic sources in Upper West Neck Creek and its boundary waters no instantaneous or geometric mean violations will occur. Scenario 3 predicts that with a reduction of 50% of the anthropogenic load, 83% violations of the geometric mean standard, 5% violations of the instantaneous standard will occur. Scenarios 4 through 6 show the models predictions for reductions that are required to reach 0% violation rate for both standards.

Table 5.6 Allocation scenarios for bacterial concentration with current loading estimates in model segment 7, West Neck Creek (Upper).

Scenario Number	Percent Reduction in Loading from Existing Conditions					Percent Violations	
	Direct Wildlife	NPS Forest / Wetland	NPS Pasture / Livestock Access / Crops	Straight Pipe / Sewer Overflow	NPS Res. / Urban	GM > 35 cfu/100ml	Single Sample > 104 cfu / 100ml
1	0	0	0	0	0	100.00	15.94
2	0	0	100	100	100	0.00	0.00
3	0	0	50	100	50	83.33	5.00
4	0	0	80	100	80	8.33	0.31
5	0	0	83	100	83	8.33	0.31
6	0	0	85	100	85	0.00	0.00

Figures 5.1 through 5.5 show the monthly instantaneous values for existing and allocated conditions for all impairments in the Virginia Beach Coastal Area. These graphs show allocated conditions in black, with existing conditions overlaid in gray.

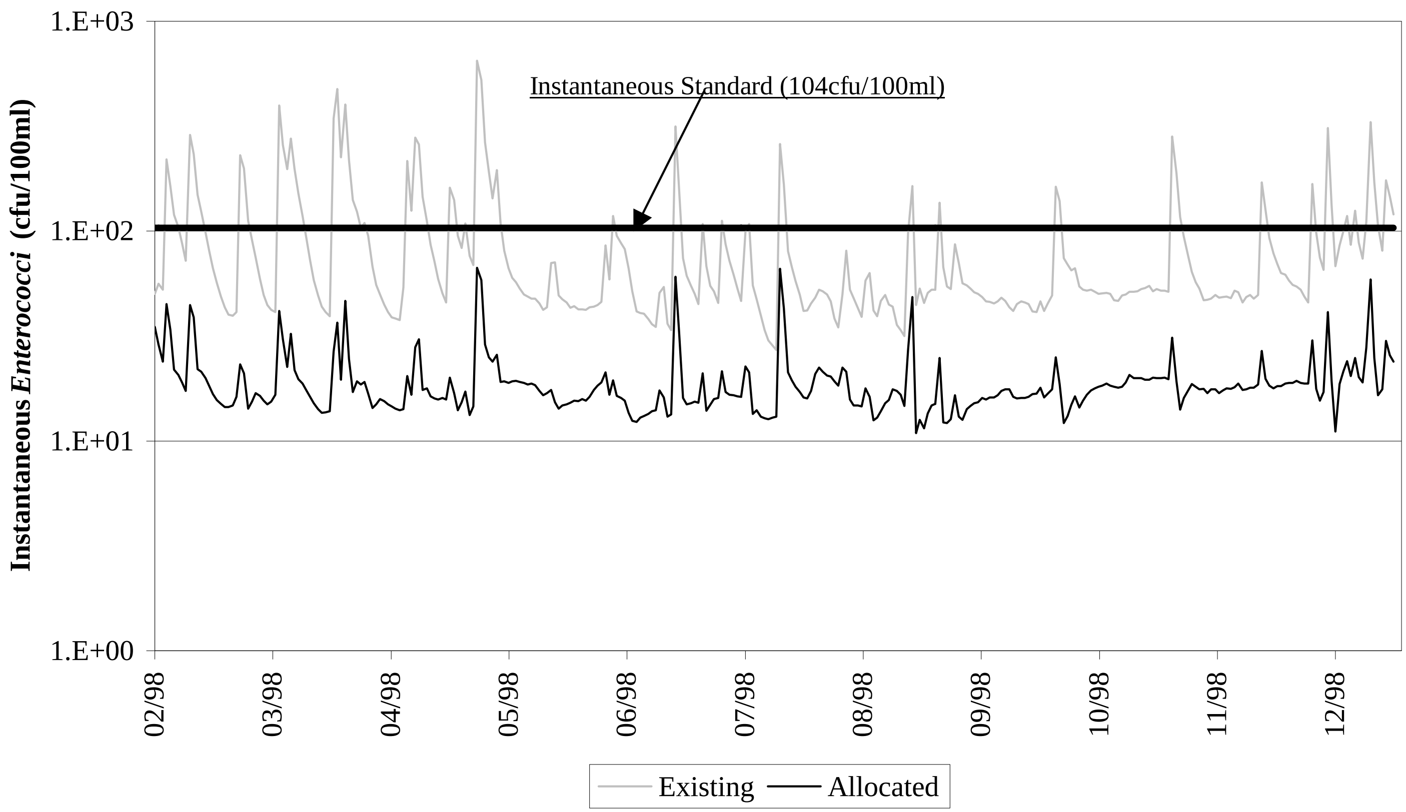


Figure 5.1 Existing and allocation scenarios of *enterococci* concentrations in model segment 7 subwatershed 5, Nawney Creek impairment.

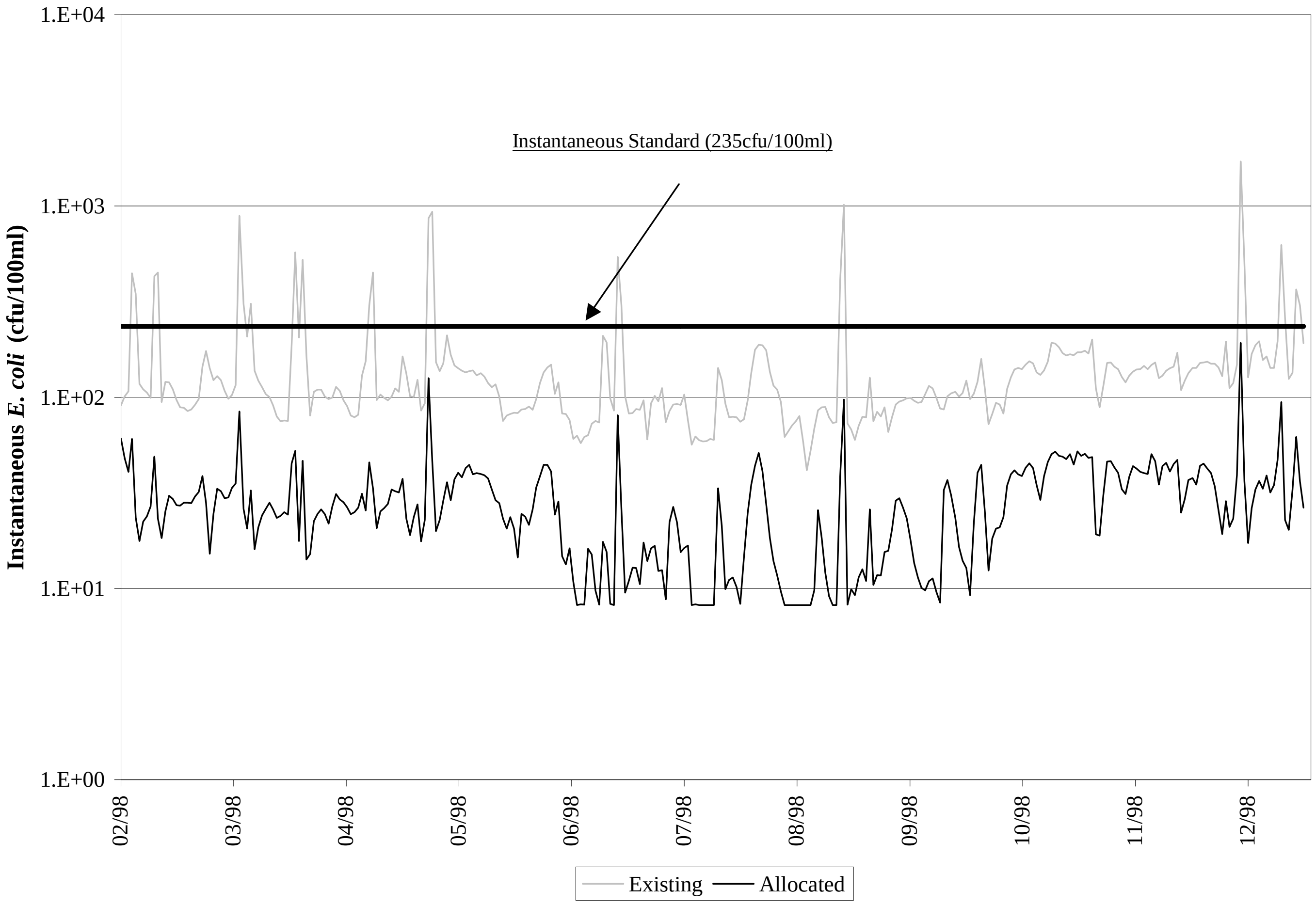


Figure 5.2 Existing and allocation scenarios of *E. coli* concentrations in model segment 7 subwatershed 22, Milldam Creek impairment.

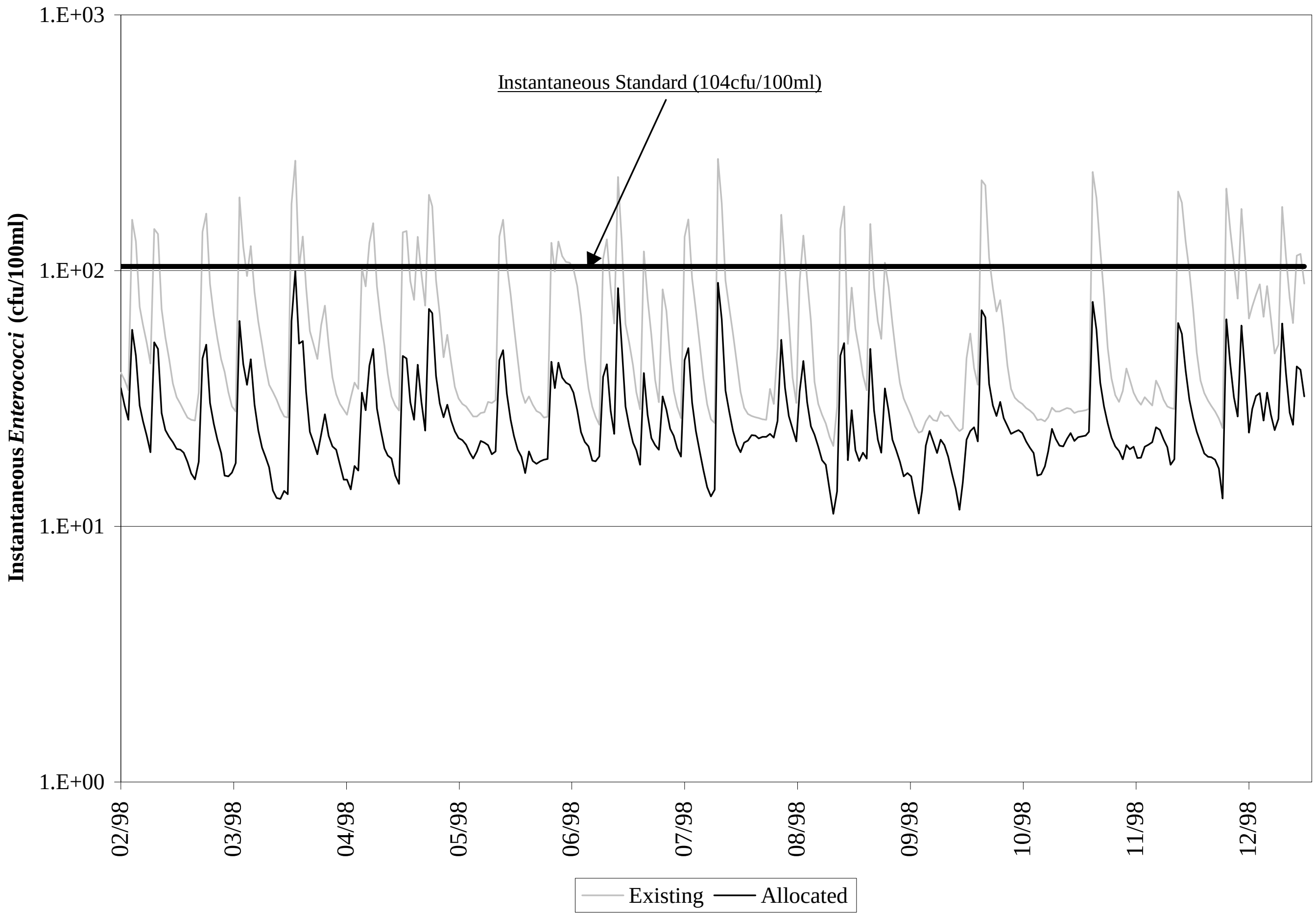


Figure 5.3 **Existing and allocation scenarios of e*nterococci* concentrations in model segment 7 subwatershed 34, London Bridge Creek impairment.**

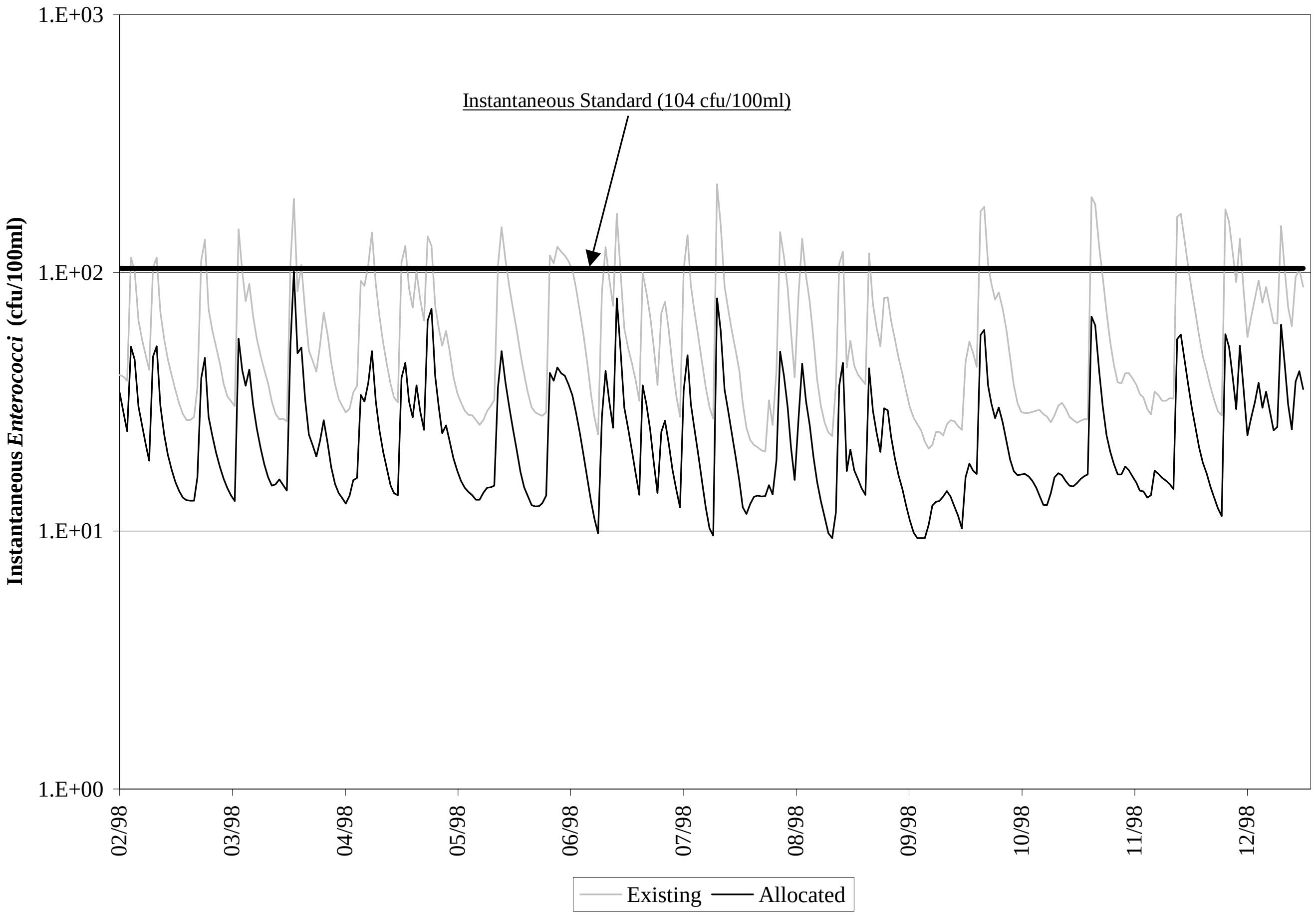


Figure 5.4 Existing and allocation scenarios of e*nterococci* concentrations in model segment 7 subwatershed 39, West Neck Creek (Upper) impairment.

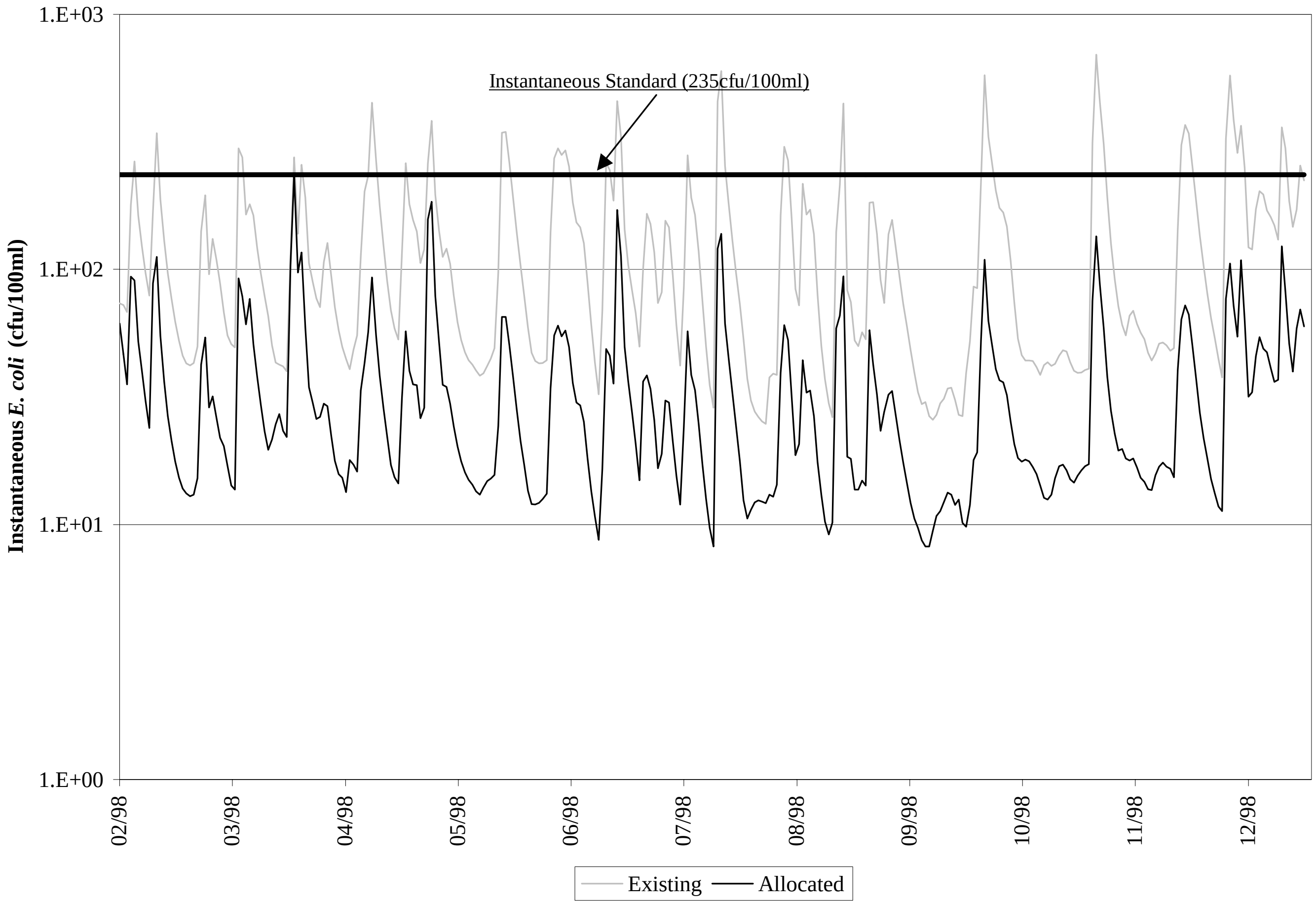


Figure 5.5 Existing and allocation scenarios of *E. coli* concentrations in model segment 7 subwatershed 11, West Neck Creek (Middle) impairment.

Figures 5.6 through 5.10 show the monthly geometric mean concentrations for existing and allocated conditions for all impairments in the Virginia Beach Coastal Area. These graphs show existing conditions in gray, with allocated conditions overlaid in black. The monthly geometric mean is calculated from the daily average *E. coli* or *enterococci* concentration, as appropriate, predicted by the water quality model, and is grouped by calendar month.

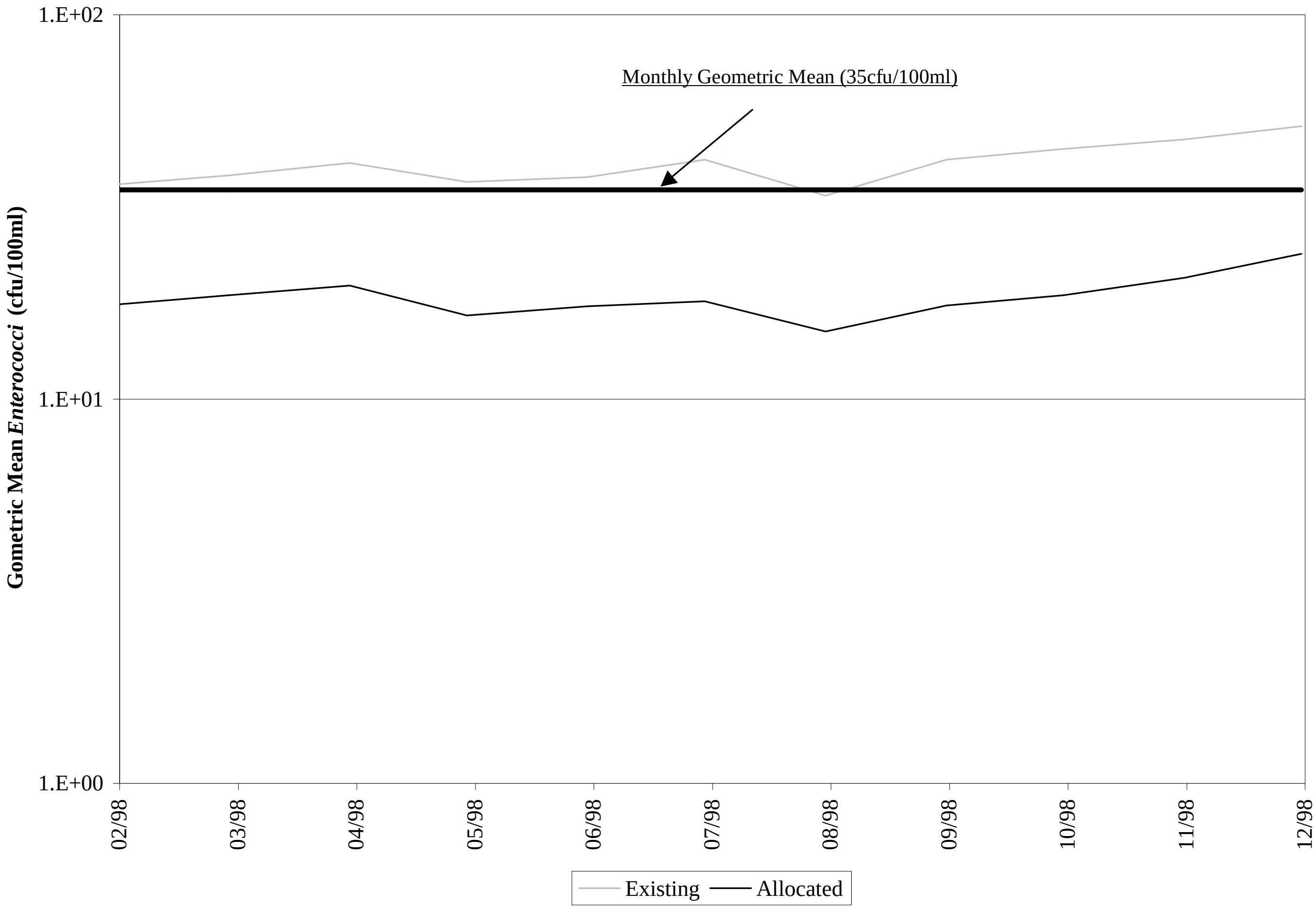


Figure 5.6 Existing and allocation scenarios of e*nterococci* concentrations in model segment 7 subwatershed 5, Nawney Creek impairment.

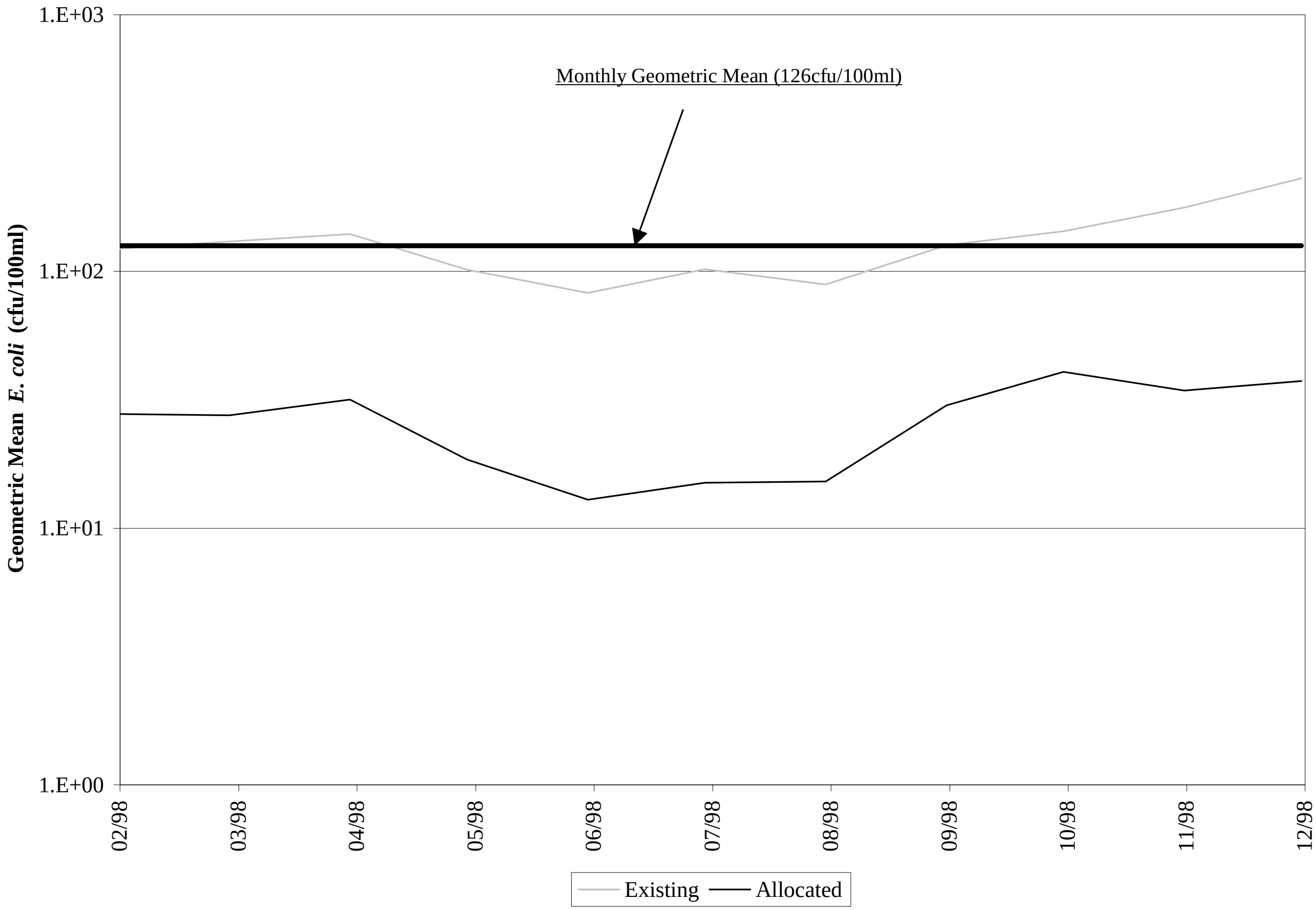


Figure 5.7 Existing and allocation scenarios of *E. coli* concentrations in model segment 7 subwatershed 22, Milldam Creek impairment.

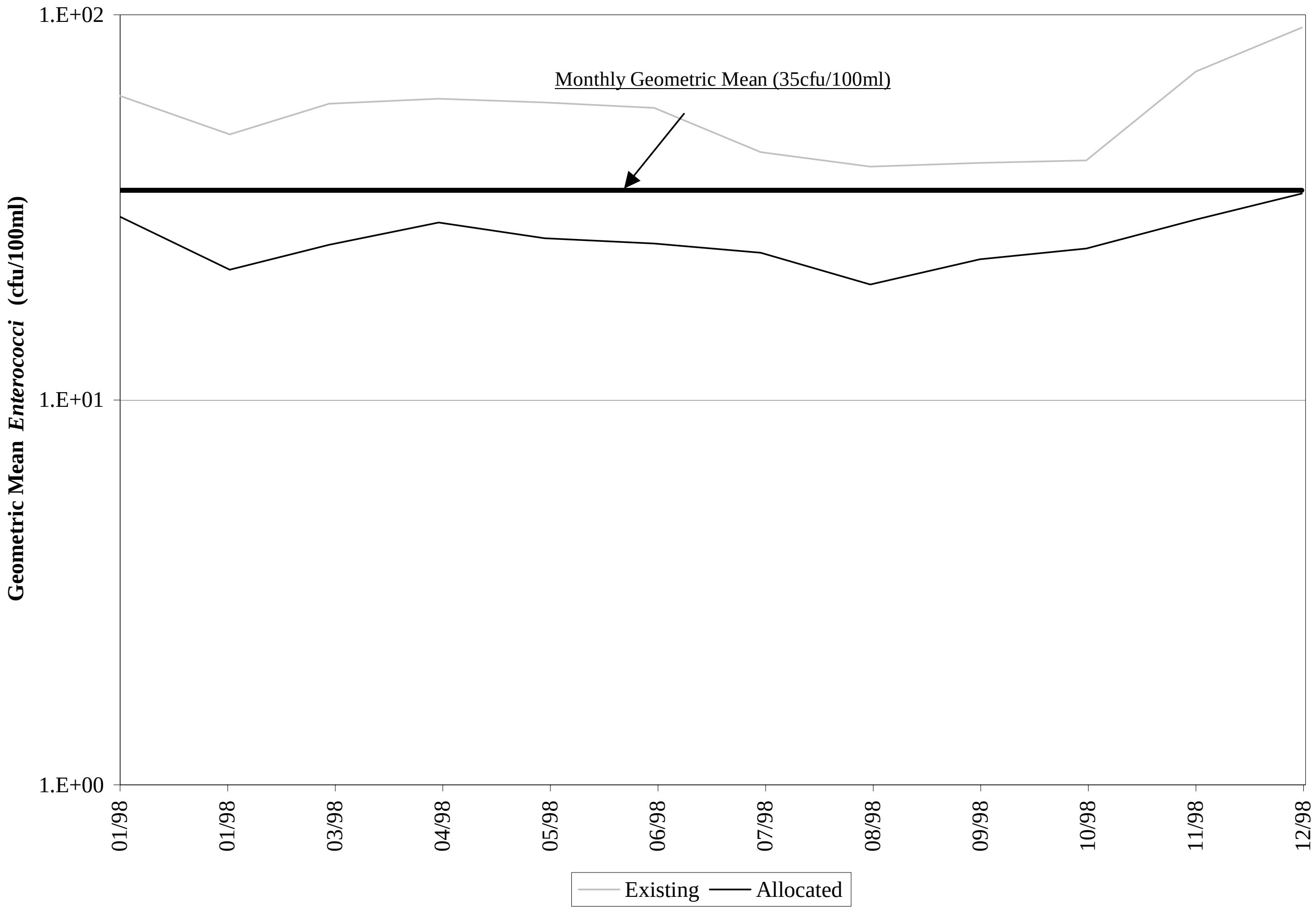


Figure 5.8 Existing and allocation scenarios of e*nterococci* concentrations in model segment 7 subwatershed 34, London Bridge Creek impairment.

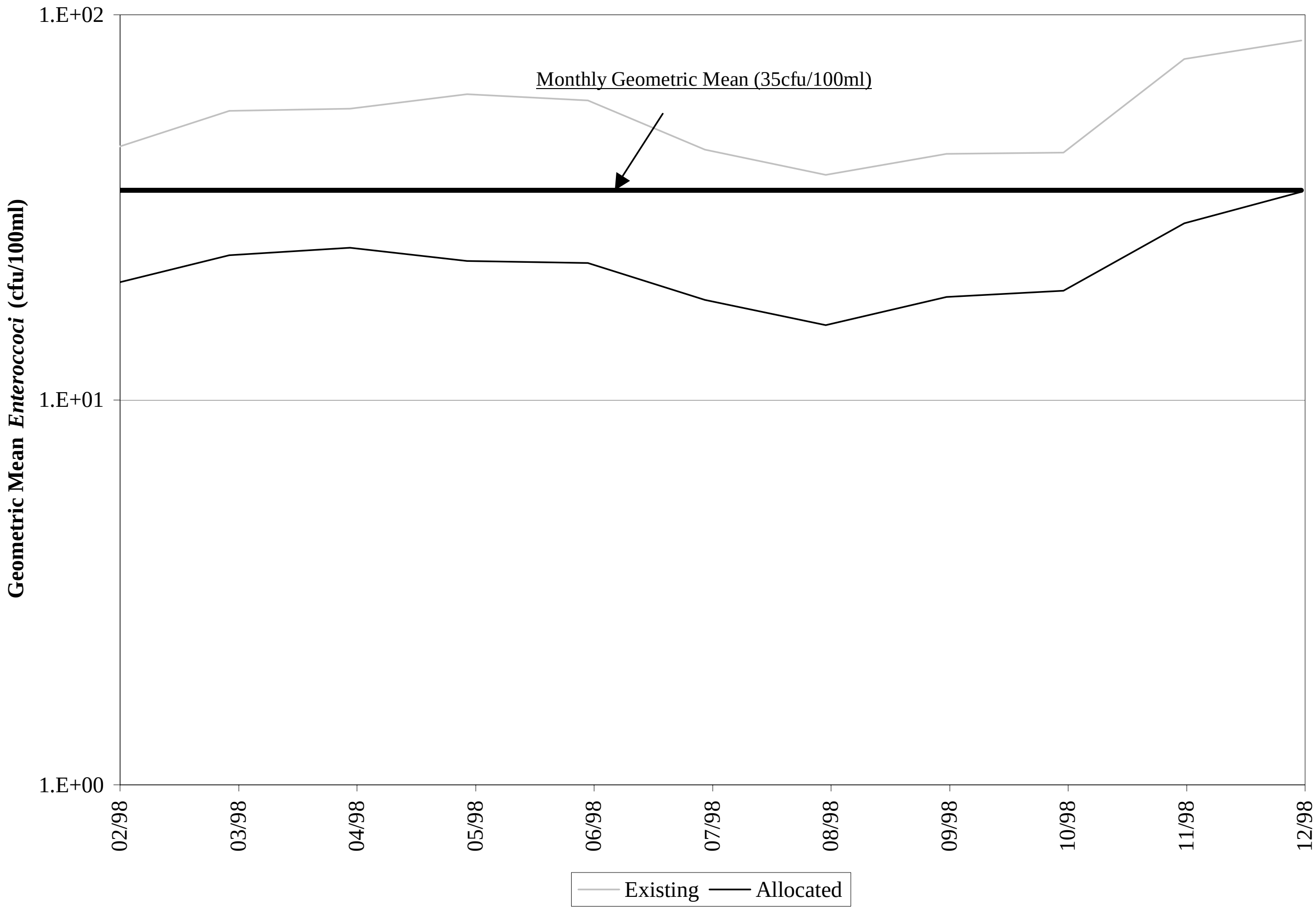


Figure 5.9 Existing and allocation scenarios of e*nterococci* concentrations in model segment 7 subwatershed 39, West Neck Creek (Upper) impairment.

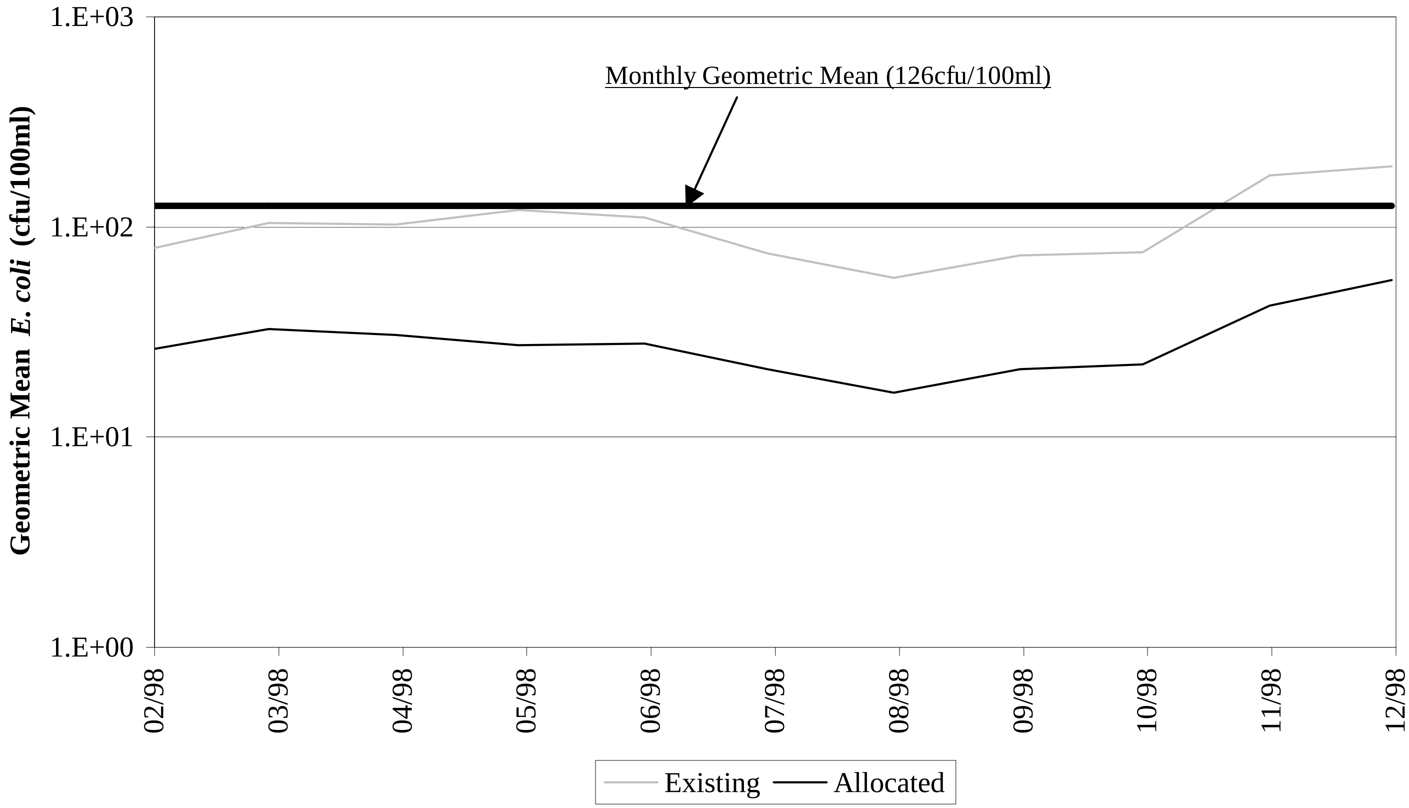


Figure 5.10 **Existing and allocation scenarios of *E. coli* concentrations in model segment 7 subwatershed 11, West Neck Creek (Middle) impairment.**

Tables 5.7 through 5.11 contain the existing and allocated loads for all the impairments in the Virginia Beach Coastal Area, reported as total annual fecal coliforms from both direct and land-based sources. The percent reduction needed to meet zero percent violations of water quality standards is given in the final column of these tables. Table 5.12 is known as the TMDL table, which gives the number of coliforms of *E. coli* that can reach the stream in a given year, and still meet existing water quality standards. These figures are broken up into Waste Load Allocation (WLA), or the portion of these coliforms that may come from permitted discharge sources (including NPS sources under an MS4 permit) and Load Allocation (LA), or the portion of these coliforms that may come from the non-permitted non-point sources existing in the watershed. The load for each MS4 permit was modeled as the load from impervious surfaces within the boundaries of the area covered by the MS4 (*e.g.*, NAS Oceana) falling within the impairment drainage area. Reductions to existing NPS loads were applied to all affected land areas, regardless of the existence of an MS4 permit.

Table 5.7 Land-based and Direct nonpoint source fecal coliform load reductions in the London Bridge & Canal #2 impairment for final allocation.

Source	Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based			
Livestock Access	5.35E+12	6.46E+11	88.00
Barren	3.09E+13	3.73E+12	88.00
Commercial	4.38E+12	5.25E+11	88.00
Cropland	2.24E+13	2.68E+12	88.00
Pasture	5.93E+13	6.87E+12	88.00
Residential	5.40E+14	6.51E+13	88.00
Water	0.00E+00	0.00E+00	0.00
Wetlands	3.34E+13	3.34E+13	0.00
Woodland	3.22E+13	3.22E+13	0.00
Direct			
Human	1.50E+13	0.00E+00	100.00
Livestock	0.00E+00	0.00E+00	100.00
Wildlife	3.55E+12	3.55E+12	0.00

Table 5.8 Land-based and Direct nonpoint source fecal coliform load reductions in the West Neck Creek (Upper) impairment for final allocation.

Source	Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based			
Livestock Access	1.27E+13	1.88E+12	85.00
Barren	1.86E+13	2.78E+12	85.00
Commercial	1.34E+13	1.98E+12	85.00
Cropland	6.00E+13	9.09E+12	85.00
Pasture	1.29E+14	1.94E+13	85.00
Residential	2.98E+14	4.49E+13	85.00
Water	0.00E+00	0.00E+00	0.00
Wetlands	1.02E+14	1.02E+14	0.00
Woodland	5.02E+13	5.02E+13	0.00
Direct			
Human	3.20E+13	0.00E+00	100.00
Livestock	0.00E+00	0.00E+00	100.00
Wildlife	3.66E+12	3.66E+12	0.00

Table 5.9 Land-based and Direct nonpoint source fecal coliform load reductions in the West Neck Creek (Middle) impairment for final allocation.

Source	Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based			
Livestock Access	1.75E+12	2.09E+11	88.00
Barren	4.47E+11	5.36E+10	88.00
Commercial	1.06E+11	1.25E+10	88.00
Cropland	8.16E+13	9.86E+12	88.00
Pasture	1.44E+13	1.73E+12	88.00
Residential	7.06E+13	8.49E+12	88.00
Water	0.00E+00	0.00E+00	0.00
Wetlands	7.12E+13	7.12E+13	0.00
Woodland	2.17E+13	2.17E+13	0.00
Direct			
Human	2.00E+13	0.00E+00	100.00
Livestock	0.00E+00	0.00E+00	100.00
Wildlife	2.03E+12	2.03E+12	0.00

Table 5.10 Land-based and Direct nonpoint source fecal coliform load reductions in the Nawney Creek impairment for final allocation.

Source	Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based			
Livestock Access	5.36E+12	8.14E+11	85.00
Commercial	1.44E+12	2.17E+11	85.00
Cropland	3.76E+14	5.67E+13	85.00
Pasture	5.42E+13	8.16E+12	85.00
Residential	3.02E+13	4.53E+12	85.00
Water	0.00E+00	0.00E+00	0.00
Wetlands	6.51E+13	6.51E+13	0.00
Woodland	9.74E+12	9.74E+12	0.00
Direct			
Human	1.10E+13	0.00E+00	100.00
Livestock	0.00E+00	0.00E+00	100.00
Wildlife	1.07E+13	1.07E+13	0.00

Table 5.11 Land-based and Direct nonpoint source fecal coliform load reductions in the Milldam Creek impairment for final allocation.

Source	Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based			
Livestock Access	1.36E+12	1.36E+10	99.00
Commercial	3.07E+09	3.07E+07	99.00
Cropland	3.65E+13	3.65E+11	99.00
Pasture	6.31E+12	6.31E+10	99.00
Residential	4.89E+12	4.89E+10	99.00
Water	0.00E+00	0.00E+00	0.00
Wetlands	8.27E+13	7.35E+12	91.00
Woodland	6.86E+12	6.22E+11	91.00
Direct			
Human	1.50E+13	0.00E+00	100.00
Livestock	1.90E+10	0.00E+00	100.00
Wildlife	2.76E+12	2.76E+12	0.00

Table 5.12 Average annual bacterial loads (cfu/year) modeled after TMDL allocation in the Virginia Beach Coastal Area watershed impairments.

Impairment	TMDL Standard	WLA (cfu/year)	LA (cfu/year)	MOS	TMDL (cfu/year)
London Bridge Creek & Canal #2	*enterococci*	2.17E+13	1.621E+12	Implicit	2.33E+13
City of Va Beach MS4 VA0088676		1.82E+13			
Oceana NAS MS4 VAR040043		3.54E+12			
Nawney Creek	*enterococci*	0.00E+00	5.09E+12		5.09E+12
Milldam Creek	*E. coli*	0.00E+00	3.86E+12		3.86E+12
West Neck Creek (Middle)	*E. coli*	0.00E+00	3.33E+13		3.33E+13
West Neck Creek (Upper)	*enterococci*	1.88E+13	2.33E+12		2.11E+13
City of Va Beach MS4 VA0088676		7.81E+12			
Oceana NAS MS4 VAR040043		1.10E+13			

6. IMPLEMENTATION

The goal of this TMDL is to establish a three-step path that will lead to attainment of water quality standards. The first step in this process is to develop TMDLs that will result in meeting water quality standards. This report represents the culmination of that effort for the bacteria impairments in the Virginia Beach Coastal Study Area. The second step is to develop a TMDL implementation plan. The final step is to implement the TMDL implementation plan (IP), and to monitor stream water quality to determine if water quality standards are being attained.

Once a TMDL has been approved by EPA and the citizen State Water Control Board, measures must be taken to reduce pollution levels in the stream. These measures, which can include the use of better treatment technology and the installation of best management practices (BMPs), are implemented in an iterative process that is described along with specific BMPs in the implementation plan. The process for developing an implementation plan has been described in the recent *Guidance Manual for Total Maximum Daily Load Implementation Plans*, published in July 2003 and available upon request from the VADEQ and VADCR TMDL project staff or at http://www.deq.state.va.us/tmdl/implans/ipguide.pdf. With successful completion of implementation plans, Virginia will be well on the way to restoring impaired waters and enhancing the value of this important resource. Additionally, development of an approved implementation plan will improve a locality's chances for obtaining financial and technical assistance during implementation.

6.1 Staged Implementation

In general, Virginia intends that the required reductions be implemented in an iterative process that first addresses those sources with the largest impact on water quality. For example, in agricultural areas of the watershed, the most promising management practice is livestock exclusion from streams. This has been shown to be very effective in lowering bacteria concentrations in streams, both by reducing the cattle deposits themselves and by providing additional riparian buffers.

Additionally, in both urban and rural areas, reducing the human bacteria loading from failing septic systems and straight pipes should be a primary implementation focus because of its health implications. This component could be implemented through education on septic tank pump-outs as well as a septic system installation/repair/replacement program and the use of alternative waste treatment systems.

In urban areas, reducing the human bacteria loading from leaking sewer lines could be accomplished through a sanitary sewer inspection and management program. Other readily implementable BMPs that might be appropriate for controlling urban wash-off from parking lots and roads may include more restrictive ordinances to reduce fecal loads from pets, improved garbage collection and control, and improved street cleaning.

The iterative implementation of BMPs in the watershed has several benefits:

1. It enables tracking of water quality improvements following BMP implementation through follow-up stream monitoring;
2. It provides a measure of quality control, given the uncertainties inherent in computer simulation modeling;
3. It provides a mechanism for developing public support through periodic updates on BMP implementation and water quality improvements;
4. It helps ensure that the most cost effective practices are implemented first; and
5. It allows for the evaluation of the adequacy of the TMDL in achieving water quality standards.

Watershed stakeholders will have opportunity to participate in the development of the TMDL implementation plan. While specific goals for BMP implementation will be established as part of the implementation plan development, the following Stage I scenarios are targeted at controllable, anthropogenic bacteria sources and can serve as starting points for targeting BMP implementation activities.

6.2 Stage I Scenarios

The goal of the Stage I scenarios is to reduce the bacteria loadings from controllable sources, excluding wildlife. The Stage I scenarios were generated with the same model setup as was used for the TMDL allocation scenarios. While specific Stage I goals for BMP implementation will be established as part of the implementation plan development process, one potential scenario is outlined below.

As presented in Chapter 5, scenarios were devised assuming reductions of 100% in all anthropogenic land-based loads, 100% reduction in sewer overflows and uncontrolled residential discharges, 100% reduction in direct livestock deposition, and a 0% reduction in wildlife direct and land-based loading to the stream. For all impairments, the model predicted violations of the water quality standards.

The Stage I water quality goal was to reduce the number of violations of the instantaneous standard in the impaired segments in the Virginia Beach Coastal Study Area to less than 10%. The model predictions for these stage I allocations are shown in Table 6.1.

Table 6.1 Reduction percentages for the Stage I implementation.

Impairment Name	Direct Wildlife	NPS Wildlife	Direct Live-stock	NPS Pasture / Livestock Access/ Cropland	NPS Res./ Urban	Straight Pipe/ Sewer Overflow	% Single Samples Exceeding Standard
London Bridge & Canal #2	0	0	-	50	50	100	9.06
Milldam Creek	0	0	100	50	50	100	5.31
Nawney Creek	0	0	-	15	15	100	5.00
West Neck Creek (Middle)	0	0	-	50	50	100	4.69
West Neck Creek (Upper)	0	0	-	50	50	100	5.00

Tables 6.2 through Table 6.6 detail the load reductions required to meet the Stage I Implementation described in Table 6.1.

Table 6.2 Nonpoint source allocations in the London Bridge and Canal #2 impairment for Stage I implementation.

Source	Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based			
Livestock Access	5.35E+12	2.67E+12	50.00
Barren	3.09E+13	1.55E+13	50.00
Commercial	4.38E+12	2.19E+12	50.00
Cropland	2.24E+13	1.12E+13	50.00
Pasture	5.40E+14	2.70E+14	50.00
Residential	5.93E+13	2.97E+13	50.00
Water	0.00E+00	0.00E+00	0.00
Wetlands	3.34E+13	3.34E+13	0.00
Woodland	3.22E+13	3.22E+13	0.00
Direct			
Human	1.50E+13	0.00E+00	100.00
Livestock	0.00E+00	0.00E+00	-
Wildlife	3.55E+12	3.55E+12	0.00

Table 6.3 Nonpoint source allocations in the West Neck Creek (Upper) impairment for Stage I implementation.

Source	Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based			
Livestock Access	1.27E+13	6.37E+12	50.00
Barren	1.86E+13	9.29E+12	50.00
Commercial	1.34E+13	6.70E+12	50.00
Cropland	6.00E+13	3.00E+13	50.00
Pasture	2.98E+14	1.49E+14	50.00
Residential	1.29E+14	6.47E+13	50.00
Water	0.00E+00	0.00E+00	0.00
Wetlands	1.02E+14	1.02E+14	0.00
Woodland	5.02E+13	5.02E+13	0.00
Direct			
Human	3.20E+13	0.00E+00	100.00
Livestock	0.00E+00	0.00E+00	-
Wildlife	3.66E+12	3.66E+12	0.00

Table 6.4 Nonpoint source allocations in the West Neck Creek (Middle) impairment for Stage I implementation.

Source	Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based			
Livestock Access	1.75E+12	8.73E+11	50.00
Barren	4.47E+11	2.23E+11	50.00
Commercial	1.06E+11	5.28E+10	50.00
Cropland	8.16E+13	4.08E+13	50.00
Pasture	7.06E+13	3.53E+13	50.00
Residential	1.44E+13	7.22E+12	50.00
Water	0.00E+00	0.00E+00	0.00
Wetlands	7.12E+13	7.12E+13	0.00
Woodland	2.17E+13	2.17E+13	0.00
Direct			
Human	2.00E+13	0.00E+00	100.00
Livestock	0.00E+00	0.00E+00	-
Wildlife	2.03E+12	2.03E+12	0.00

Table 6.5 Nonpoint source allocations in the Nawney Creek impairment for Stage I implementation.

Source	Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based			
Livestock Access	5.36E+12	4.56E+12	15.00
Commercial	1.60E+12	1.36E+12	15.00
Cropland	3.76E+14	3.19E+14	15.00
Pasture	3.02E+13	2.57E+13	15.00
Residential	5.42E+13	4.61E+13	15.00
Water	0.00E+00	0.00E+00	0.00
Wetlands	6.51E+13	6.51E+13	0.00
Woodland	9.74E+12	9.74E+12	0.00
Direct			
Human	1.10E+13	0.00E+00	100.00
Livestock	0.00E+00	0.00E+00	-
Wildlife	1.07E+13	1.07E+13	0.00

Table 6.6 Nonpoint source allocations in the Milldam Creek impairment for Stage I implementation.

Source	Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based			
Livestock Access	1.36E+12	6.80E+11	50.00
Commercial	3.07E+09	1.53E+09	50.00
Cropland	3.65E+13	1.83E+13	50.00
Pasture	4.89E+12	2.45E+12	50.00
Residential	6.31E+12	3.16E+12	50.00
Water	0.00E+00	0.00E+00	0.00
Wetlands	8.27E+13	8.27E+13	0.00
Woodland	6.86E+12	6.86E+12	0.00
Livestock Access	1.50E+13	0.00E+00	100.00
Direct			
Human	1.90E+10	0.00E+00	100.00
Livestock	2.09E+12	2.09E+12	0.00
Wildlife	1.36E+12	6.80E+11	50.00

The development of the implementation plan is expected to be an iterative process, with monitoring data refining its final design. Subsequent refinements will be made as the progress toward meeting milestones and the expressed TMDL goals are assessed. As practices are implemented, periodic analyses of water quality conditions will be conducted to evaluate the progress toward meeting end goals.

6.3 Reasonable Assurance for Implementation

6.3.1 Follow-up Monitoring

VADEQ will continue monitoring the Virginia Beach Coastal Study Area in accordance with its ambient monitoring program to evaluate reductions in fecal bacteria counts and the effectiveness of TMDL implementation in attainment of water quality standards. VADEQ solicits assistance from citizen monitoring groups in support of follow-up water quality monitoring for bacterial TMDLs.

6.3.2 Regulatory Framework

While Section 303(d) of the Clean Water Act and current EPA regulations do not require the development of TMDL implementation plans as part of the TMDL process, they do require reasonable assurance that the load and wasteload allocations can and will be implemented. Additionally, Virginia's 1997 Water Quality Monitoring, Information and Restoration Act (WQMIRA) directs the State Water Control Board to "develop and implement a plan to achieve fully supporting status for impaired waters" (Section 62.1-44.19.7). WQMIRA also establishes that the implementation plan shall include the date of expected achievement of water quality objectives, measurable goals, corrective actions necessary and the associated costs, benefits and environmental impacts of addressing the impairments. EPA outlines the minimum elements of an approvable implementation plan in its 1999 *Guidance for Water Quality-Based Decisions: The TMDL Process*. The listed elements include implementation actions/management measures, timelines, legal or regulatory controls, time required to attain water quality standards, monitoring plans and milestones for attaining water quality standards.

Watershed stakeholders will have opportunities to provide input and to participate in the development of the implementation plan, which will also be supported by the regional and local offices of VADEQ, VADCR, and other cooperating agencies.

Once developed, VADEQ will take TMDL implementation plans to the State Water Control Board (SWCB) for approval as the plan for implementing the pollutant allocations and reductions contained in the TMDLs. Also, VADEQ will request SWCB authorization to incorporate the TMDL implementation plan into the appropriate Water Quality Management Plan (WQMP) in accordance with the CWA's Section 303(e). In response to a Memorandum of Understanding (MOU) between EPA and VADEQ, VADEQ submitted a draft Continuous Planning Process to EPA in which VADEQ commits to regularly updating the WQMPs. Thus, the WQMPs will be, among other things, the repository for all TMDLs and TMDL implementation plans developed within a river basin.

6.3.3 Stormwater Permits

It is the intention of the Commonwealth that the TMDL will be implemented using existing regulations and programs. One of these regulations is the Virginia Pollutant Discharge Elimination System (VPDES) Permit Regulation (9 VAC 25-31-10 et seq.).

Section 9 VAC 25-31-120 describes the requirements for storm water discharges. Also, federal regulations state in 40 CFR §122.44(k) that NPDES permit conditions may consist of "Best management practices to control or abate the discharge of pollutants when: (2) Numeric effluent limitations are infeasible…".

For MS4/VPDES general permits, VADEQ expects revisions to the permittee's Storm Water Management Plans to specifically address the TMDL pollutants of concern. VADEQ anticipates that BMP effectiveness would be determined through ambient in-stream monitoring. This is in accordance with recent EPA guidance (EPA Memorandum on TMDLs and Stormwater Permits, dated November 22, 2002). If future monitoring indicates no improvement in stream water quality, the permit could require the MS4 to expand or better tailor its BMPs to achieve the TMDL reductions. However, only failing to implement the required BMPs would be considered a violation of the permit. DEQ acknowledges that it may not be possible to meet the existing water quality standard because of the wildlife issue associated with a number of bacteria TMDLs (see section 6.3.5 below). At some future time, it may therefore become necessary to investigate the stream's use designation and adjust the water quality criteria through a Use Attainability Analysis. Any changes to the TMDL resulting from water quality standards change in the Virginia Beach Coastal Study Area would be reflected in the permittee's Storm Water Management Plan required by the MS4/VPDES permit.

Additional information on Virginia's Storm Water Phase 2 program and a downloadable menu of Best Management Practices and Measurable Goals Guidance can be found at http://www.deq.state.va.us/water/bmps.html.

6.3.4 Implementation Funding Sources

One potential source of funding for TMDL implementation is Section 319 of the Clean Water Act. Section 319 funding is a major source of funds for Virginia's Nonpoint Source Management Program. Other funding sources for implementation include the U.S. Department of Agriculture's Conservation Reserve Enhancement Program (CREP) and Environmental Quality Incentive Program (EQIP), the Virginia State Revolving Loan Program, and the Virginia Water Quality Improvement Fund. The TMDL

Implementation Plan Guidance Manual contains additional information on funding sources, as well as government agencies that might support implementation efforts and suggestions for integrating TMDL implementation with other watershed planning efforts.

6.3.5 Addressing Wildlife Contributions

In some streams for which TMDLs have been developed, water quality modeling indicates that even after removal of bacteria sources other than wildlife, the stream will not attain standards under all flow regimes at all times. As is the case for the Virginia Beach Coastal Study Area, these streams may not be able to attain standards without some reduction in wildlife load. **Virginia and EPA are not proposing the reduction of wildlife to allow for the attainment of water quality standards.**

To address this issue, Virginia has proposed (during its recent triennial water quality standards review) a new "secondary contact" category for protecting the recreational use in state waters. On March 25, 2003, the Virginia State Water Control Board adopted criteria for "secondary contact recreation" which means "a water-based form of recreation, the practice of which has a low probability for total body immersion or ingestion of waters (examples include but are not limited to wading, boating and fishing)". These new criteria became effective February 12, 2004 and can be found at http://www.deq.state.va.us/wqs/rule.html.

In order for the new criteria to apply to a specific stream segment, the primary contact recreational use must be removed. To remove a designated use, the state must demonstrate 1) that the use is not an existing use, 2) that downstream uses are protected, and 3) that the source of bacterial contamination is natural and uncontrollable by effluent limitations and by implementing cost-effective and reasonable best management practices for nonpoint source control (9 VAC 25-260-10). This, and other, information is collected through a special study called a Use Attainability Analysis (UAA). All site-specific criteria or designated use changes must be adopted as amendments to the water quality standards regulations. Watershed stakeholders and EPA will be able to provide comment during this process. Additional information can be obtained at http://www.deq.state.va.us/wqs/WQS03AUG.pdf.

Based on the above, EPA and Virginia have developed a process to address the wildlife issue. First in this process is the development of a Stage I scenario such as those presented previously in this chapter. The pollutant reductions in the Stage I scenario are targeted only at the controllable, anthropogenic bacteria sources identified in the TMDL, setting aside control strategies for wildlife except for cases of over-populations. During the implementation of the Stage I scenario, all controllable sources would be reduced to the maximum extent practicable using the iterative approach described in Section 6.1 above. VADEQ will re-assess water quality in the stream during and subsequent to the implementation of the Stage I scenario to determine if the water quality standard is attained. This effort will also evaluate if the modeling assumptions were correct. If water quality standards are not being met, a UAA may be initiated to reflect the presence of naturally high bacteria levels due to uncontrollable sources. In some cases, the effort may never have to go to the UAA phase because the water quality standard exceedances attributed to wildlife in the model may have been very small and infrequent and within the margin of error.

7. PUBLIC PARTICIPATION

The development of the Virginia Beach Coastal TMDLs greatly benefited from public participation. This section details the involvement for the Virginia Beach Coastal Area.

7.1 Tidal Section

In addition to the two public meetings, there were two Technical Advisory Committee (TAC) meetings. Table 7.1 details the public participation throughout the project.

The first TAC meeting took place on August 26, 2004 at the VADEQ Tidewater Regional Office in Virginia Beach, VA. There were 14 attendees representing government agencies and MapTech, Inc. The second TAC meeting took place on December 2, 2004 and was attended by 10 people.

The first public meeting took place on October 20, 2004 at the VADEQ Tidewater Regional Office, Virginia Beach, VA; 13 people attended. The meeting was publicized in the *Virginia Register*. There was a 30 day-public comment period and no written comments were received.

The final public meeting took place on January 20, 2005 at the Advanced Technology Center, Tidewater Community College Virginia Beach Campus, Virginia Beach, VA. The meeting was publicized in the *Virginia Register.* 15 people attended the meeting. Topics discussed were an overview of the TMDL process, TMDL results, allocation scenarios, BST results, and implementation plan development. There was a 30-day public comment period.

Table 7.1 Public participation during TMDL development for the Tidal section watershed.

Date	Location	Attendance[1]	Type	Format
8/26/04	DEQ Tidewater Regional Office 5636 Southern Blvd Virginia Beach, VA	14	1st TAC meeting	Open to public at large
10/20/04	DEQ Tidewater Regional Office 5636 Southern Blvd Virginia Beach, VA	13	1st Public meeting	Open to public at large
12/2/04	DEQ Tidewater Regional Office 5636 Southern Blvd Virginia Beach, VA	10	2nd TAC meeting	
1/20/05	Advanced Technology Center Tidewater Community College – Virginia Beach Campus Virginia Beach, VA	15	Final Public meeting	Open to public at large

[1]The number of attendants is estimated from sign up sheets provided at each meeting. These numbers are known to underestimate the actual attendance.

Public participation during the implementation plan development process will include the formation of committees and open public meetings. Public participation is critical to promote reasonable assurances that the implementation activities will occur. A steering committee will have the expressed purpose of formulating the TMDL implementation plan. The major stakeholders were identified during the development of this TMDL. The committee will consist of, but not be limited to, representatives from the Department of Environmental Quality, Department of Conservation and Recreation, Department of Health, local agricultural community, local residents, and local governments. This committee will have responsibility for identifying corrective actions that are founded in practicality, establish a time line to ensure expeditious implementation, and set measurable goals and milestones for attaining water quality standards.

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GLOSSARY

Note: All entries in italics are taken from USEPA (1998).

303(d). A section of the Clean Water Act of 1972 requiring states to identify and list water bodies that do not meet the states' water quality standards.

Allocations. *That portion of a receiving water's loading capacity attributed to one of its existing or future pollution sources (nonpoint or point) or to natural background sources. (A wasteload allocation [WLA] is that portion of the loading capacity allocated to an existing or future point source, and a load allocation [LA] is that portion allocated to an existing or future nonpoint source or to natural background levels. Load allocations are best estimates of the loading, which can range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting loading.)*

Ambient water quality. Natural concentration of water quality constituents prior to mixing of either point or nonpoint source load of contaminants. Reference ambient concentration is used to indicate the concentration of a chemical that will not cause adverse impact on human health.

Anthropogenic*. Pertains to the [environmental] influence of human activities.*

Antidegradation Policies*. Policies that are part of each states water quality standards. These policies are designed to protect water quality and provide a method of assessing activities that might affect the integrity of waterbodies.*

Aquatic ecosystem*. Complex of biotic and abiotic components of natural waters. The aquatic ecosystem is an ecological unit that includes the physical characteristics (such as flow or velocity and depth), the biological community of the water column and benthos, and the chemical characteristics such as dissolved solids, dissolved oxygen, and nutrients. Both living and nonliving components of the aquatic ecosystem interact and influence the properties and status of each component.*

Assimilative capacity. *The amount of contaminant load that can be discharged to a specific waterbody without exceeding water quality standards or criteria. Assimilative capacity is used to define the ability of a waterbody to naturally absorb and use a discharged substance without impairing water quality or harming aquatic life.*

Background levels. *Levels representing the chemical, physical, and biological conditions that would result from natural geomorphological processes such as weathering or dissolution.*

Bacteria. *Single-celled microorganisms. Bacteria of the coliform group are considered the primary indicators of fecal contamination and are often used to assess water quality.*

Bacterial decomposition. *Breakdown by oxidation, or decay, of organic matter by heterotrophic bacteria. Bacteria use the organic carbon in organic matter as the energy source for cell synthesis.*

Bacterial source tracking (BST). A collection of scientific methods used to track sources of fecal contamination.

Best management practices (BMPs). *Methods, measures, or practices determined to be reasonable and cost-effective means for a landowner to meet certain, generally nonpoint source, pollution control needs. BMPs include structural and nonstructural controls and operation and maintenance procedures.*

Bioassessment. Evaluation of the condition of an ecosystem that uses biological surveys and other direct measurements of the resident biota. **(2)**

Biological Integrity. A waterbody's ability to support and maintain a balanced, integrated adaptive assemblage of organisms with species composition, diversity, and functional organization comparable to that of similar natural, or non-impacted habitat.

Biosolids. Biologically treated solids originating from municipal wastewater treatment plants.

Biometric. (Biological Metric) The study of biological phenomena by measurements and statistics.

Box and whisker plot. A graphical representation of the mean, lower quartile, upper quartile, upper limit, lower limit, and outliers of a data set.

Calibration. *The process of adjusting model parameters within physically defensible ranges until the resulting predictions give a best possible good fit to observed data.*

Causal analysis. A process in which data and other information are organized and evaluated using quantitative and logical techniques to determine the likely cause of an observed condition. (2)

Causal association. A correlation or other association between measures or observations of two entities or processes which occurs because of an underlying causal relationship. (2)

Causal mechanism. The process by which a cause induces an effect. (2)

Causal relationship. The relationship between a cause and its effect. (2)

Cause. 1. That which produces an effect (a general definition).

2. A stressor or set of stressors that occur at an intensity, duration and frequency of exposure that results in a change in the ecological condition (a SI-specific definition). (2)

CE-QUAL-W2. A two dimensional, longitudinal/vertical, hydrodynamic and water quality model. Because the model assumes lateral homogeneity, it is best suited for long and narrow waterbodies exhibiting longitudinal and vertical water quality gradients. The model has been applied to rivers, lakes, reservoirs, estuaries and combinations thereof.

Channel. *A natural stream that conveys water; a ditch or channel excavated for the flow of water.*

Chloride. *An atom of chlorine in solution; an ion bearing a single negative charge.*

Clean Water Act (CWA). *The Clean Water Act (formerly referred to as the Federal Water Pollution Control Act or Federal Water Pollution Control Act Amendments of 1972), Public Law 92-500, as amended by Public Law 96-483 and Public Law 97-117, 33 U.S.C. 1251 et seq. The Clean Water Act (CWA) contains a number of provisions to restore and maintain the quality of the nation's water resources. One of these provisions is Section 303(d), which establishes the TMDL program.*

Coefficient of determination. Represents the proportion of the total sample variability around y that is explained by the linear relationship between *y* and *x*. (In simple linear regression, it may also be computed as the square of the coefficient of correlation *r.)* (3)

Concentration. *Amount of a substance or material in a given unit volume of solution; usually measured in milligrams per liter (mg/L) or parts per million (ppm).*

Concentration-based limit. *A limit based on the relative strength of a pollutant in a waste stream, usually expressed in milligrams per liter (mg/L).*

Concentration-response model. A quantitative (usually statistical) model of the relationship between the concentration of a chemical to which a population or community of organisms is exposed and the frequency or magnitude of a biological response. (2)

Confluence. The point at which a river and its tributary flow together.

Contamination. *The act of polluting or making impure; any indication of chemical, sediment, or biological impurities.*

Continuous discharge. *A discharge that occurs without interruption throughout the operating hours of a facility, except for infrequent shutdowns for maintenance, process changes, or other similar activities.*

Conventional pollutants. *As specified under the Clean Water Act, conventional contaminants include suspended solids, coliform bacteria, high biochemical oxygen demand, pH, and oil and grease.*

Conveyance. A measure of the of the water carrying capacity of a channel section. It is directly proportional to the discharge in the channel section.

Cost-share program. *A program that allocates project funds to pay a percentage of the cost of constructing or implementing a best management practice. The remainder of the costs is paid by the producer(s).*

Cross-sectional area. *Wet area of a waterbody normal to the longitudinal component of the flow.*

Critical condition. *The critical condition can be thought of as the "worst case" scenario of environmental conditions in the waterbody in which the loading expressed in the TMDL for the pollutant of concern will continue to meet water quality standards. Critical conditions are the combination of environmental factors (e.g., flow, temperature, etc.) that results in attaining and maintaining the water quality criterion and has an acceptably low frequency of occurrence.*

Decay. *The gradual decrease in the amount of a given substance in a given system due to various sink processes including chemical and biological transformation, dissipation to other environmental media, or deposition into storage areas.*

Decomposition. *Metabolic breakdown of organic materials; the formation of by-products of decomposition releases energy and simple organic and inorganic compounds. See also Respiration.*

Designated uses. *Those uses specified in water quality standards for each waterbody or segment whether or not they are being attained.*

Deterministic model. *A model that does not include built-in variability: same input will always result in the same output.*

Dilution. *The addition of some quantity of less-concentrated liquid (water) that results in a decrease in the original concentration.*

Direct runoff. *Water that flows over the ground surface or through the ground directly into streams, rivers, and lakes.*

Discharge. *Flow of surface water in a stream or canal, or the outflow of groundwater from a flowing artesian well, ditch, or spring. Can also apply to discharge of liquid effluent from a facility or to chemical emissions into the air through designated venting mechanisms.*

Discharge Monitoring Report (DMR). *Report of effluent characteristics submitted by a municipal or industrial facility that has been granted an NPDES discharge permit.*

Discharge permits (under NPDES). *A permit issued by the U.S. EPA or a state regulatory agency that sets specific limits on the type and amount of pollutants that a municipality or industry can discharge to receiving water; it also includes a compliance schedule for achieving those limits. The permit process was established under the National Pollutant Discharge Elimination System, under provisions of the Federal Clean Water Act.*

Dispersion. *The spreading of chemical or biological constituents, including pollutants, in various directions at varying velocities depending on the differential in-stream flow characteristics.*

Diurnal. *Actions or processes that have a period or a cycle of approximately one tidal-day or are completed within a 24-hour period and that recur every 24 hours. Also, the occurrence of an activity/process during the day rather than the night.*

DNA. Deoxyribonucleic acid. The genetic material of cells and some viruses.

Domestic wastewater. *Also called sanitary wastewater, consists of wastewater discharged from residences and from commercial, institutional, and similar facilities.*

Drainage basin. *A part of a land area enclosed by a topographic divide from which direct surface runoff from precipitation normally drains by gravity into a receiving water. Also referred to as a watershed, river basin, or hydrologic unit.*

Dynamic model. *A mathematical formulation describing and simulating the physical behavior of a system or a process and its temporal variability.*

Dynamic simulation. *Modeling of the behavior of physical, chemical, and/or biological phenomena and their variations over time.*

Ecoregion. A region defined in part by its shared characteristics. These include meteorological factors, elevation, plant and animal speciation, landscape position, and soils.

Ecosystem. *An interactive system that includes the organisms of a natural community association together with their abiotic physical, chemical, and geochemical environment.*

Effluent. *Municipal sewage or industrial liquid waste (untreated, partially treated, or completely treated) that flows out of a treatment plant, septic system, pipe, etc.*

Effluent guidelines. *The national effluent guidelines and standards specify the achievable effluent pollutant reduction that is attainable based upon the performance of treatment technologies employed within an industrial category. The National Effluent Guidelines Program was established with a phased approach whereby industry would first be required to meet interim limitations based on best practicable control technology currently available for existing sources (BPT). The second level of effluent limitations to be attained by industry was referred to as best available technology economically achievable (BAT), which was established primarily for the control of toxic pollutants.*

Effluent limitation. *Restrictions established by a state or EPA on quantities, rates, and concentrations in pollutant discharges.*

Empirical model. *Use of statistical techniques to discern patterns or relationships underlying observed or measured data for large sample sets. Does not account for physical dynamics of waterbodies.*

Endpoint. *An endpoint (or indicator/target) is a characteristic of an ecosystem that may be affected by exposure to a stressor. Assessment endpoints and measurement endpoints are two distinct types of endpoints commonly used by resource managers. An assessment endpoint is the formal expression of a valued environmental characteristic and should have societal relevance (an indicator). A measurement endpoint is the expression of an observed or measured response to a stress or disturbance. It is a measurable environmental characteristic that is related to the valued environmental characteristic chosen as the assessment endpoint. The numeric criteria that are part of traditional water quality standards are good examples of measurement endpoints (targets).*

Enhancement. *In the context of restoration ecology, any improvement of a structural or functional attribute.*

Erosion. The detachment and transport of soil particles by water and wind. Sediment resulting from soil erosion represents the single largest source of nonpoint pollution in the United States.

Eutrophication. The process of enrichment of water bodies by nutrients. Waters receiving excessive nutrients may become eutrophic, are often undesirable for recreation, and may not support normal fish populations.

Evapotranspiration. The combined effects of evaporation and transpiration on the water balance. Evaporation is water loss into the atmosphere from soil and water surfaces. Transpiration is water loss into the atmosphere as part of the life cycle of plants.

Existing use. *Use actually attained in the waterbody on or after November 28, 1975, whether or not it is included in the water quality standards (40 CFR 131.3).*

Fate of pollutants. *Physical, chemical, and biological transformation in the nature and changes of the amount of a pollutant in an environmental system. Transformation processes are pollutant-specific. Because they have comparable kinetics, different formulations for each pollutant are not required.*

Fecal Coliform. Indicator organisms (organisms indicating presence of pathogens) associated with the digestive tract.

Feedlot. *A confined area for the controlled feeding of animals. Tends to concentrate large amounts of animal waste that cannot be absorbed by the soil and, hence, may be carried to nearby streams or lakes by rainfall runoff.*

First-order kinetics. *The type of relationship describing a dynamic reaction in which the rate of transformation of a pollutant is proportional to the amount of that pollutant in the environmental system.*

Flux. *Movement and transport of mass of any water quality constituent over a given period of time. Units of mass flux are mass per unit time.*

General Standard. A narrative standard that ensures the general health of state waters. All state waters, including wetlands, shall be free from substances attributable to sewage, industrial waste, or other waste in concentrations, amounts, or combinations which contravene established standards or interfere directly or indirectly with designated uses of such water or which are inimical or harmful to human, animal, plant, or aquatic life (9VAC25-260-20). (4)

Geometric mean. A measure of the central tendency of a data set that minimizes the effects of extreme values.

GIS. Geographic Information System. A system of hardware, software, data, people, organizations and institutional arrangements for collecting, storing, analyzing and disseminating information about areas of the earth. (Dueker and Kjerne, 1989)

Ground water. *The supply of fresh water found beneath the earths surface, usually in aquifers, which supply wells and springs. Because ground water is a major source of drinking water, there is growing concern over contamination from leaching agricultural or industrial pollutants and leaking underground storage tanks.*

HSPF. Hydrological Simulation Program – Fortran. A computer simulation tool used to mathematically model nonpoint source pollution sources and movement of pollutants in a watershed.

Hydrograph*. A graph showing variation of stage (depth) or discharge in a stream over a period of time.*

Hydrologic cycle. *The circuit of water movement from the atmosphere to the earth and its return to the atmosphere through various stages or processes, such as precipitation, interception, runoff, infiltration, storage, evaporation, and transpiration.*

Hydrology. *The study of the distribution, properties, and effects of water on the earth's surface, in the soil and underlying rocks, and in the atmosphere.*

Hyetograph. *Graph of rainfall rate versus time during a storm event.*

IMPLND. An impervious land segment in HSPF. It is used to model land covered by impervious materials, such as pavement.

Indicator. *A measurable quantity that can be used to evaluate the relationship between pollutant sources and their impact on water quality.*

Indicator organism. *An organism used to indicate the potential presence of other (usually pathogenic) organisms. Indicator organisms are usually associated with the other organisms, but are usually more easily sampled and measured.*

Indirect causation. The induction of effects through a series of cause-effect relationships, so that the impaired resource may not even be exposed to the initial cause. (2)

Indirect effects. Changes in a resource that is due to a series of cause-effect relationships rather than to direct exposure to a contaminant or other stressor. (2)

Infiltration capacity. *The capacity of a soil to allow water to infiltrate into or through it during a storm.*

In situ. *In place; in situ measurements consist of measurements of components or processes in a full-scale system or a field, rather than in a laboratory.*

Interflow. Runoff that travels just below the surface of the soil.

Isolate. An inbreeding biological population that is isolated from similar populations by physical or other means.

Leachate. *Water that collects contaminants as it trickles through wastes, pesticides, or fertilizers. Leaching can occur in farming areas, feedlots, and landfills and can result in hazardous substances entering surface water, ground water, or soil.*

Limits (upper and lower). The lower limit equals the lower quartile – 1.5x(upper quartile – lower quartile), and the upper limit equals the upper quartile + 1.5x(upper quartile – lower quartile). Values outside these limits are referred to as outliers.

Loading, Load, Loading rate. *The total amount of material (pollutants) entering the system from one or multiple sources; measured as a rate in weight per unit time.*

Load allocation (LA). *The portion of a receiving waters loading capacity attributed either to one of its existing or future nonpoint sources of pollution or to natural background sources. Load allocations are best estimates of the loading, which can range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting the loading. Wherever possible, natural and nonpoint source loads should be distinguished (40 CFR 130.2(g)).*

Loading capacity (LC). *The greatest amount of loading a water can receive without violating water quality standards.*

Margin of safety (MOS). *A required component of the TMDL that accounts for the uncertainty about the relationship between the pollutant loads and the quality of the receiving waterbody (CWA Section 303(d)(1)(C)). The MOS is normally incorporated into the conservative assumptions used to develop TMDLs (generally within the calculations or models) and approved by EPA either individually or in state/EPA agreements. If the MOS needs to be larger than that which is allowed through the conservative assumptions, additional MOS can be added as a separate component of the TMDL (in this case, quantitatively, a TMDL = LC = WLA + LA + MOS).*

Mass balance. *An equation that accounts for the flux of mass going into a defined area and the flux of mass leaving the defined area. The flux in must equal the flux out.*

Mass loading. *The quantity of a pollutant transported to a waterbody.*

Mathematical model. *A system of mathematical expressions that describe the spatial and temporal distribution of water quality constituents resulting from fluid transport and the one or more individual processes and interactions within some prototype aquatic ecosystem. A mathematical water quality model is used as the basis for waste load allocation evaluations.*

Mean. The sum of the values in a data set divided by the number of values in the data set.

Metrics. Indices or parameters used to measure some aspect or characteristic of a water body's biological integrity. The metric changes in some predictable way with changes in water quality or habitat condition.

MGD. Million gallons per day. A unit of water flow, whether discharge or withdraw.

Mitigation. *Actions taken to avoid, reduce, or compensate for the effects of environmental damage. Among the broad spectrum of possible actions are those that restore, enhance, create, or replace damaged ecosystems.*

Model. Mathematical representation of hydrologic and water quality processes. Effects of land use, slope, soil characteristics, and management practices are included.

Monitoring. *Periodic or continuous surveillance or testing to determine the level of compliance with statutory requirements and/or pollutant levels in various media or in humans, plants, and animals.*

Mood's Median Test. A nonparametric (distribution-free) test used to test the equality of medians from two or more populations.

Multivariate Regression. A functional relationship between 1 dependent variable and multiple independent variables that are often empirically determined from data and are used especially to predict values of one variable when given values of the others.

Narrative criteria. *Nonquantitative guidelines that describe the desired water quality goals.*

National Pollutant Discharge Elimination System (NPDES). *The national program for issuing, modifying, revoking and re-issuing, terminating, monitoring, and enforcing permits, and imposing and enforcing pretreatment requirements, under sections 307, 402, 318, and 405 of the Clean Water Act.*

Natural waters. *Flowing water within a physical system that has developed without human intervention, in which natural processes continue to take place.*

Nonpoint source. *Pollution that originates from multiple sources over a relatively large area. Nonpoint sources can be divided into source activities related to either land or water use including failing septic tanks, improper animal-keeping practices, forest practices, and urban and rural runoff.*

Numeric targets. *A measurable value determined for the pollutant of concern, which, if achieved, is expected to result in the attainment of water quality standards in the listed waterbody.*

Numerical model. Model that approximates a solution of governing partial differential equations, which describe a natural process. The approximation uses a numerical discretization of the space and time components of the system or process.

Organic matter. *The organic fraction that includes plant and animal residue at various stages of decomposition, cells and tissues of soil organisms, and substances synthesized by the soil population. Commonly determined as the amount of organic material contained in a soil or water sample.*

Parameter. A numerical descriptive measure of a population. Since it is based on the observations of the population, its value is almost always unknown.

Peak runoff. *The highest value of the stage or discharge attained by a flood or storm event; also referred to as flood peak or peak discharge.*

PERLND. A pervious land segment in HSPF. It is used to model a particular land use segment within a subwatershed (e.g. pasture, urban land, or crop land).

Permit. *An authorization, license, or equivalent control document issued by EPA or an approved federal, state, or local agency to implement the requirements of an environmental regulation; e.g., a permit to operate a wastewater treatment plant or to operate a facility that may generate harmful emissions.*

Permit Compliance System (PCS). *Computerized management information system that contains data on NPDES permit-holding facilities. PCS keeps extensive records on more than 65,000 active water-discharge permits on sites located throughout the nation. PCS tracks permit, compliance, and enforcement status of NPDES facilities.*

Phased/staged approach. *Under the phased approach to TMDL development, load allocations and wasteload allocations are calculated using the best available data and information recognizing the need for additional monitoring data to accurately characterize sources and loadings. The phased approach is typically employed when nonpoint sources dominate. It provides for the implementation of load reduction strategies while collecting additional data.*

Point source. *Pollutant loads discharged at a specific location from pipes, outfalls, and conveyance channels from either municipal wastewater treatment plants or industrial waste treatment facilities. Point sources can also include pollutant loads contributed by tributaries to the main receiving water stream or river.*

Pollutant. *Dredged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt, and industrial, municipal, and agricultural waste discharged into water. (CWA section 502(6)).*

Pollution. *Generally, the presence of matter or energy whose nature, location, or quantity produces undesired environmental effects. Under the Clean Water Act, for example, the term is defined as the man-made or man-induced alteration of the physical, biological, chemical, and radiological integrity of water.*

Postaudit. *A subsequent examination and verification of a model's predictive performance following implementation of an environmental control program.*

Privately owned treatment works. *Any device or system that is (a) used to treat wastes from any facility whose operator is not the operator of the treatment works and (b) not a publicly owned treatment works.*

Public comment period. *The time allowed for the public to express its views and concerns regarding action by EPA or states (e.g., a* Federal Register *notice of a proposed rule-making, a public notice of a draft permit, or a Notice of Intent to Deny).*

Publicly owned treatment works (POTW). *Any device or system used in the treatment (including recycling and reclamation) of municipal sewage or industrial wastes of a liquid nature that is owned by a state or municipality. This definition includes sewers, pipes, or other conveyances only if they convey wastewater to a POTW providing treatment.*

Quartile. The 25^{th}, 50^{th}, and 75^{th} percentiles of a data set. A percentile (p) of a data set ordered by magnitude is the value that has at most p% of the measurements in the data set below it, and (100-p)% above it. The 50^{th} quartile is also known as the median. The 25^{th} and 75^{th} quartiles are referred to as the lower and upper quartiles, respectively.

Raw sewage. Untreated municipal sewage.

Reach. Segment of a stream or river.

Receiving waters. *Creeks, streams, rivers, lakes, estuaries, ground water formations, or other bodies of water into which surface water and/or treated or untreated waste are discharged, either naturally or in man-made systems.*

Reference Conditions. The chemical, physical, or biological quality or condition exhibited at either a single site or an aggregation of sites that are representative of non-impaired conditions for a watershed of a certain size, land use distribution, and other related characteristics. Reference conditions are used to describe reference sites.

Reserve capacity. *Pollutant loading rate set aside in determining stream waste load allocation, accounting for uncertainty and future growth.*

Residence time. *Length of time that a pollutant remains within a section of a stream or river. The residence time is determined by the streamflow and the volume of the river reach or the average stream velocity and the length of the river reach.*

Restoration. *Return of an ecosystem to a close approximation of its presumed condition prior to disturbance.*

Riparian areas. *Areas bordering streams, lakes, rivers, and other watercourses. These areas have high water tables and support plants that require saturated soils during all or part of the year. Riparian areas include both wetland and upland zones.*

Riparian zone. *The border or banks of a stream. Although this term is sometimes used interchangeably with floodplain, the riparian zone is generally regarded as relatively narrow compared to a floodplain. The duration of flooding is generally much shorter, and the timing less predictable, in a riparian zone than in a river floodplain.*

Roughness coefficient. *A factor in velocity and discharge formulas representing the effects of channel roughness on energy losses in flowing water. Manning's "n" is a commonly used roughness coefficient.*

Runoff. *That part of precipitation, snowmelt, or irrigation water that runs off the land into streams or other surface water. It can carry pollutants from the air and land into receiving waters.*

Seasonal Kendall test. A statistical tool used to test for trends in data, which is unaffected by seasonal cycles.

Sediment. In the context of water quality, soil particles, sand, and minerals dislodged from the land and deposited into aquate systems as a result of erosion.

Septic system. *An on-site system designed to treat and dispose of domestic sewage. A typical septic system consists of a tank that receives waste from a residence or business and a drain field or subsurface absorption system consisting of a series of percolation lines for the disposal of the liquid effluent. Solids (sludge) that remain after decomposition by bacteria in the tank must be pumped out periodically.*

Sewer*. A channel or conduit that carries wastewater and storm water runoff from the source to a treatment plant or receiving stream. Sanitary sewers carry household, industrial, and commercial waste. Storm sewers carry runoff from rain or snow. Combined sewers handle both.*

Simulation. *The use of mathematical models to approximate the observed behavior of a natural water system in response to a specific known set of input and forcing conditions. Models that have been validated, or verified, are then used to predict the response of a natural water system to changes in the input or forcing conditions.*

Slope. *The degree of inclination to the horizontal. Usually expressed as a ratio, such as 1:25 or 1 on 25, indicating one unit vertical rise in 25 units of horizontal distance, or in a decimal fraction (0.04), degrees (2 degrees 18 minutes), or percent (4 percent).*

Source. An origination point, area, or entity that releases or emits a stressor. A source can alter the normal intensity, frequency, or duration of a natural attribute, whereby the attribute then becomes a stressor. (2)

Spatial segmentation. *A numerical discretization of the spatial component of a system into one or more dimensions; forms the basis for application of numerical simulation models.*

Staged Implementation. A process that allows for the evaluation of the adequacy of the TMDL in achieving the water quality standard. As stream monitoring continues to occur, staged or phased implementation allows for water quality improvements to be recorded as they are being achieved. It also provides a measure of quality control, and it helps to ensure that the most cost-effective practices are implemented first.

Stakeholder. Any person with a vested interest in the TMDL development.

Standard. In reference to water quality (*e.g.* 200 cfu/100 ml geometric mean limit).

Standard deviation. A measure of the variability of a data set. The positive square root of the variance of a set of measurements.

Standard error. The standard deviation of a distribution of a sample statistic, esp. when the mean is used as the statistic.

Statistical significance. An indication that the differences being observed are not due to random error. The p-value indicates the probability that the differences are due to random error (i.e. a low p-value indicates statistical significance).

Steady-state model. *Mathematical model of fate and transport that uses constant values of input variables to predict constant values of receiving water quality concentrations. Model variables are treated as not changing with respect to time.*

Stepwise regression. All possible one-variable models of the form $E(y) = B_0 + B_1 x_1$ are fit and the "best" x_1 is selected based on the *t*-test for B_1. Next, two-variable models of the form $E(y) = B_0 + B_1 x_1 + B_2 x_i$ are fit (where x_i is the variable selected in the first step): the "second best" x_i is selected based on the test for B_2. The process continues in this fashion until no more "important" *x*'s can be added to the model. (3)

Storm runoff. *Storm water runoff, snowmelt runoff, and surface runoff and drainage; rainfall that does not evaporate or infiltrate the ground because of impervious land surfaces or a soil infiltration rate lower than rainfall intensity, but instead flows onto adjacent land or into waterbodies or is routed into a drain or sewer system.*

Streamflow. *Discharge that occurs in a natural channel. Although the term "discharge" can be applied to the flow of a canal, the word "streamflow" uniquely describes the discharge in a surface stream course. The term "streamflow" is more general than "runoff" since streamflow may be applied to discharge whether or not it is affected by diversion or regulation.*

Stream Reach. A straight portion of a stream.

Stream restoration. *Various techniques used to replicate the hydrological, morphological, and ecological features that have been lost in a stream because of urbanization, farming, or other disturbance.*

Surface area. *The area of the surface of a waterbody; best measured by planimetry or the use of a geographic information system.*

Surface runoff. *Precipitation, snowmelt, or irrigation water in excess of what can infiltrate the soil surface and be stored in small surface depressions; a major transporter of nonpoint source pollutants.*

Surface water. *All water naturally open to the atmosphere (rivers, lakes, reservoirs, ponds, streams, impoundments, seas, estuaries, etc.) and all springs, wells, or other collectors directly influenced by surface water.*

Technology-based standards. *Effluent limitations applicable to direct and indirect sources that are developed on a category-by-category basis using statutory factors, not including water quality effects.*

Timestep. An increment of time in modeling terms. The smallest unit of time used in a mathematical simulation model (*e.g*. 15-minutes, 1-hour, 1-day).

Topography. *The physical features of a geographic surface area including relative elevations and the positions of natural and man-made features.*

Total Maximum Daily Load (TMDL). *The sum of the individual wasteload allocations (WLAs) for point sources, load allocations (LAs) for nonpoint sources and natural background, plus a margin of safety (MOS). TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures that relate to a state's water quality standard.*

TMDL Implementation Plan. A document required by Virginia statute detailing the suite of pollution control measures needed to remediate an impaired stream segment. The plans are also required to include a schedule of actions, costs, and monitoring. Once implemented, the plan should result in the previously impaired water meeting water quality standards and achieving a "fully supporting" use support status.

Transport of pollutants (in water). *Transport of pollutants in water involves two main processes: (1) advection, resulting from the flow of water, and (2) dispersion, or transport due to turbulence in the water.*

TRC. Total Residual Chlorine. A measure of the effectiveness of chlorinating treated waste water effluent.

Tributary. *A lower order-stream compared to a receiving waterbody. "Tributary to" indicates the largest stream into which the reported stream or tributary flows.*

Urban Runoff. Surface runoff originating from an urban drainage area including streets, parking lots, and rooftops.

Validation (of a model). *Process of determining how well the mathematical model's computer representation describes the actual behavior of the physical processes under investigation. A validated model will have also been tested to ascertain whether it accurately and correctly solves the equations being used to define the system simulation.*

Variance. A measure of the variability of a data set. The sum of the squared deviations (observation – mean) divided by (number of observations) – 1.

VADACS. Virginia Department of Agriculture and Consumer Services.

VADCR. Virginia Department of Conservation and Recreation.

VADEQ. Virginia Department of Environmental Quality.

VDH. Virginia Department of Health.

Wasteload allocation (WLA). *The portion of a receiving waters' loading capacity that is allocated to one of its existing or future point sources of pollution. WLAs constitute a type of water quality-based effluent limitation (40 CFR 130.2(h)).*

Wastewater. *Usually refers to effluent from a sewage treatment plant. See also Domestic wastewater.*

Wastewater treatment. *Chemical, biological, and mechanical procedures applied to an industrial or municipal discharge or to any other sources of contaminated water to remove, reduce, or neutralize contaminants.*

Water quality. *The biological, chemical, and physical conditions of a waterbody. It is a measure of a waterbody's ability to support beneficial uses.*

Water quality-based effluent limitations (WQBEL). *Effluent limitations applied to dischargers when technology-based limitations alone would cause violations of water quality standards. Usually WQBELs are applied to discharges into small streams.*

Water quality-based permit*. A permit with an effluent limit more stringent than one based on technology performance. Such limits might be necessary to protect the designated use of receiving waters (e.g., recreation, irrigation, industry, or water supply).*

Water quality criteria. *Levels of water quality expected to render a body of water suitable for its designated use, composed of numeric and narrative criteria. Numeric criteria are scientifically derived ambient concentrations developed by EPA or states for various pollutants of concern to protect human health and aquatic life. Narrative criteria are statements that describe the desired water quality goal. Criteria are based on specific* *levels of pollutants that would make the water harmful if used for drinking, swimming, farming, fish production, or industrial processes.*

Water quality standard. *Law or regulation that consists of the beneficial designated use or uses of a waterbody, the numeric and narrative water quality criteria that are necessary to protect the use or uses of that particular waterbody, and an antidegradation statement.*

Watershed. *A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.*

WQIA. Water Quality Improvement Act.

APPENDIX A

FREQUENCY ANALYSIS OF WATER QUALITY SAMPLING DATA

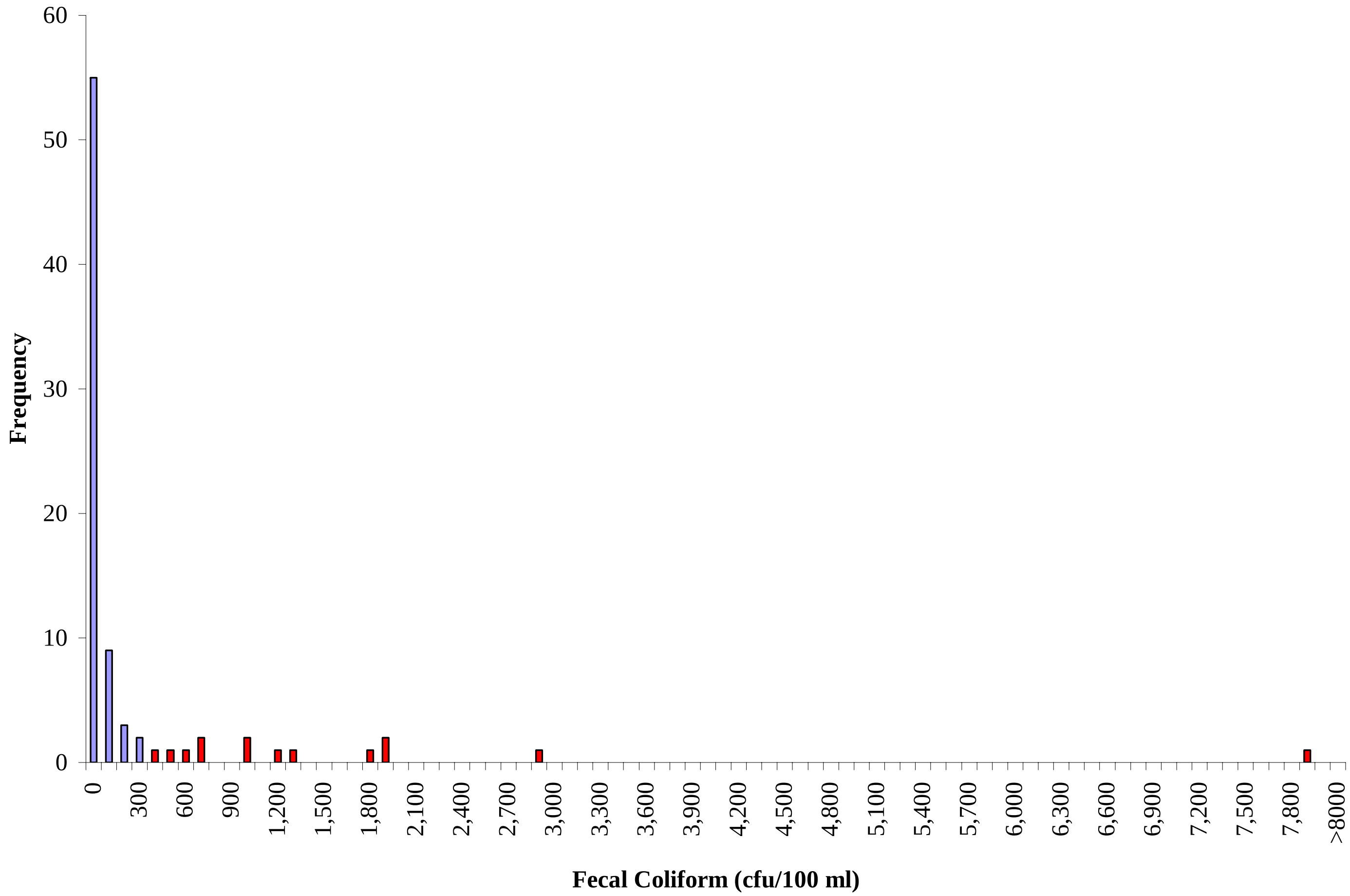

Figure A.1 **Frequency analysis of fecal coliform concentrations at station 5BMLD001.92 in the Milldam Creek impairment for period September 1995 to March 2004.**

*Red indicates a value which violates the listing standard of 400 cfu/100 ml.

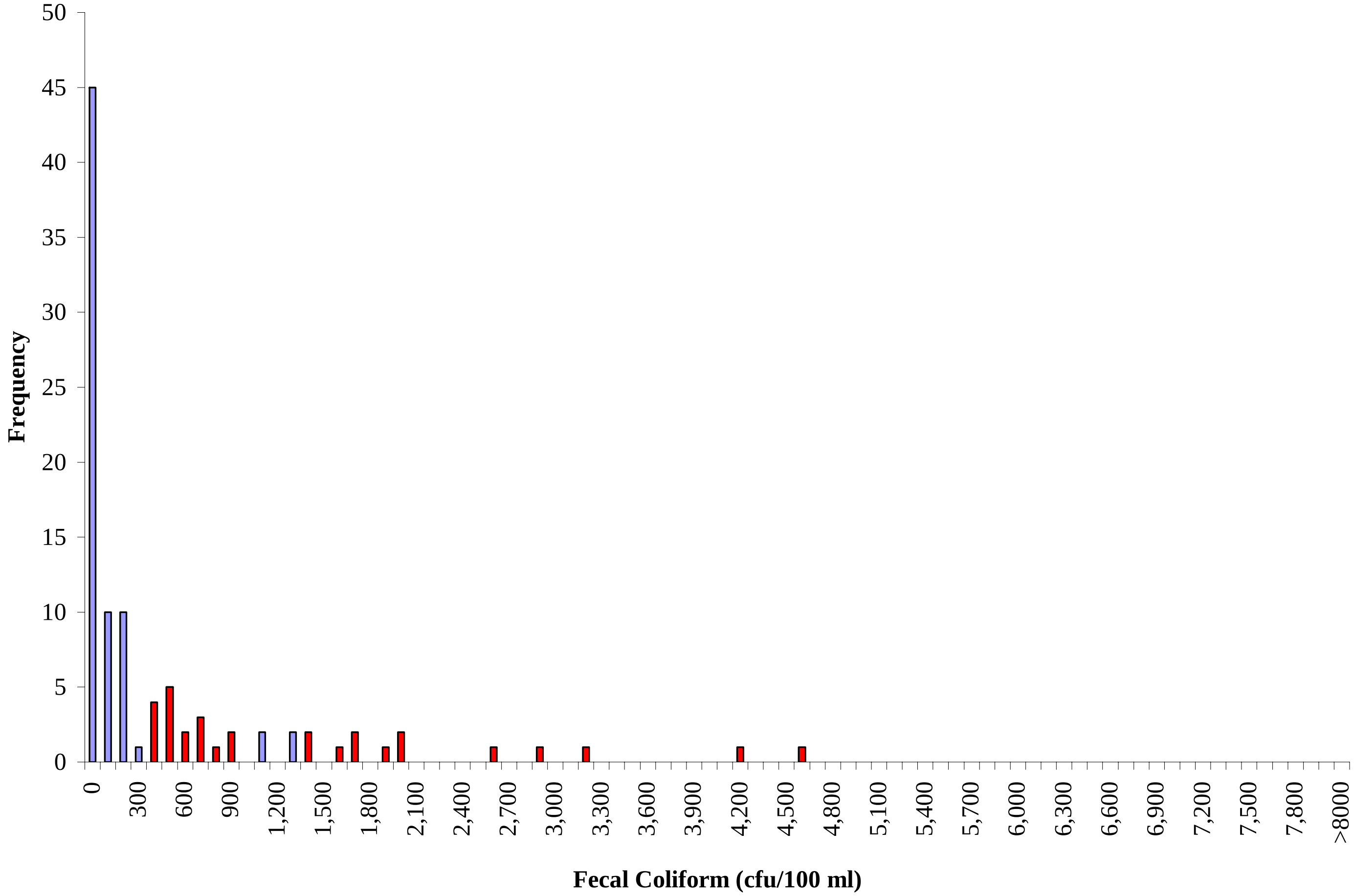

Figure A.2 Frequency analysis of fecal coliform concentrations at station 5BNWN000.00 in the Nawney Creek impairment for period June 1993 to March 2004.

*Red indicates a value which violates the listing standard of 400 cfu/100 ml.

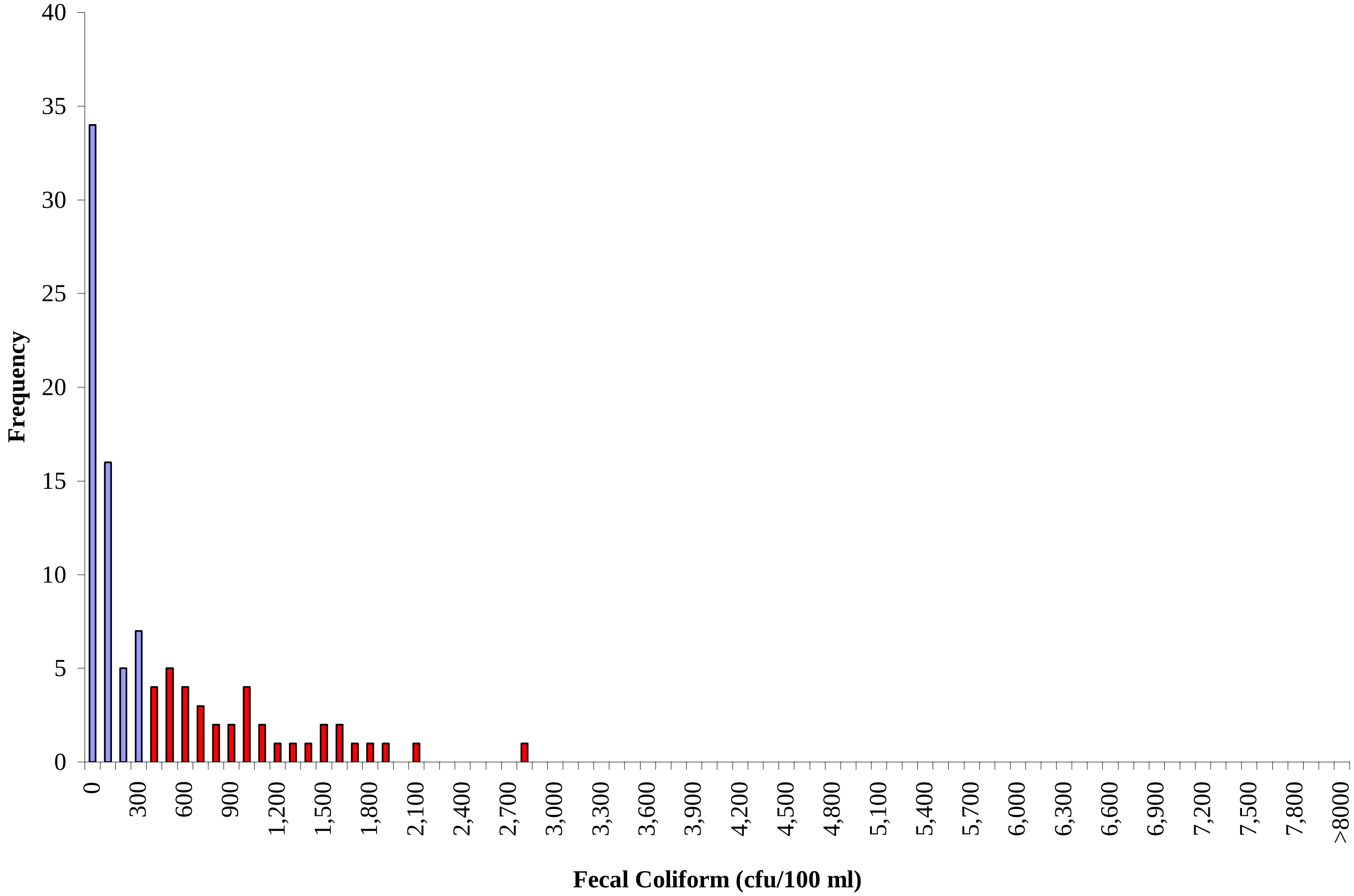

Figure A.3 Frequency analysis of fecal coliform concentrations at station 5BNWN001.84 in the Nawney Creek impairment for period June 1993 to March 2004.

*Red indicates a value which violates the listing standard of 400 cfu/100 ml.

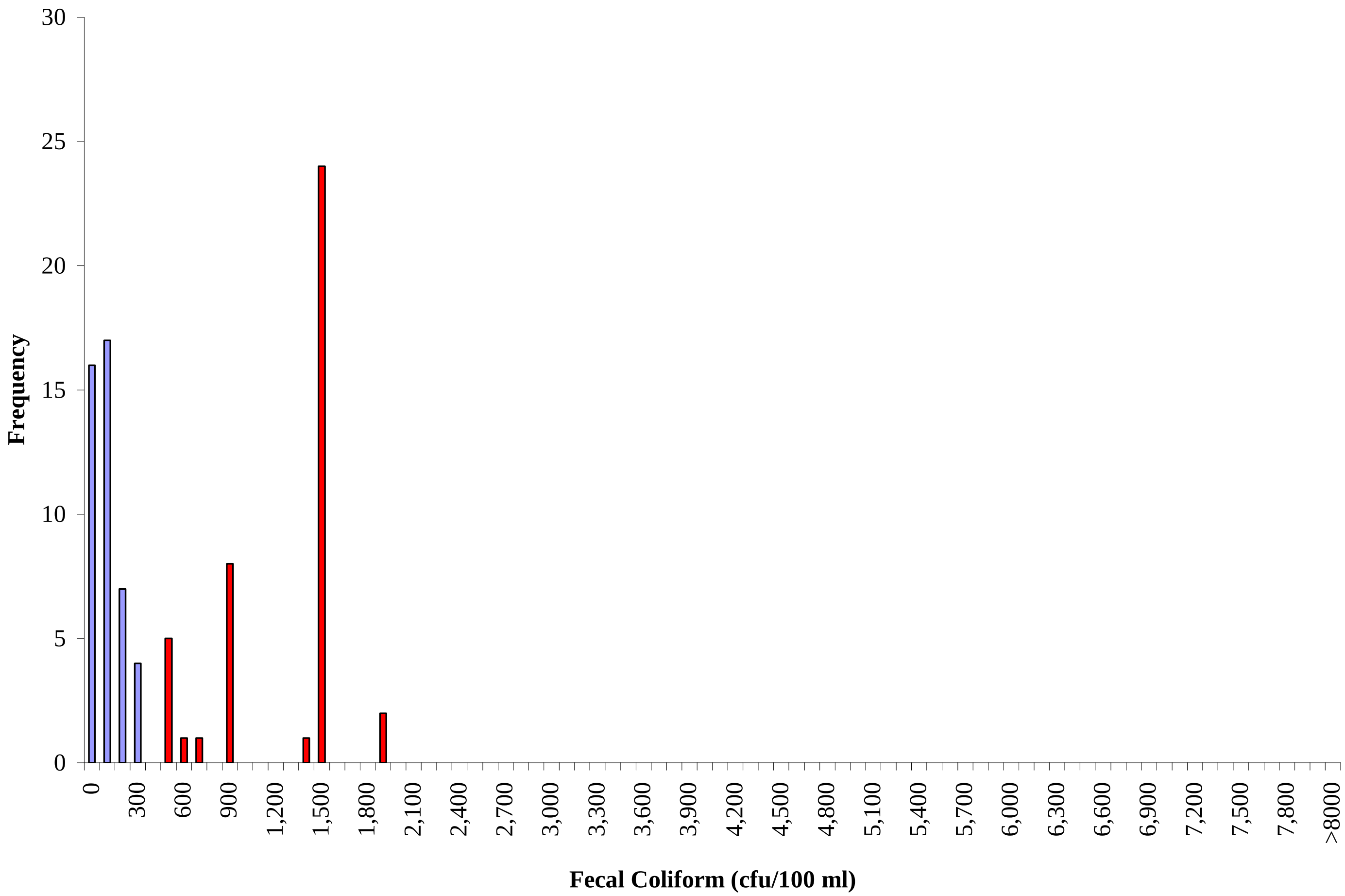

Figure A.4 Frequency analysis of fecal coliform concentrations at station 5BWNC010.02 in the West Neck Creek (Upper) impairment for period September 1995 to March 2004.

*Red indicates a value which violates the listing standard of 400 cfu/100 ml.

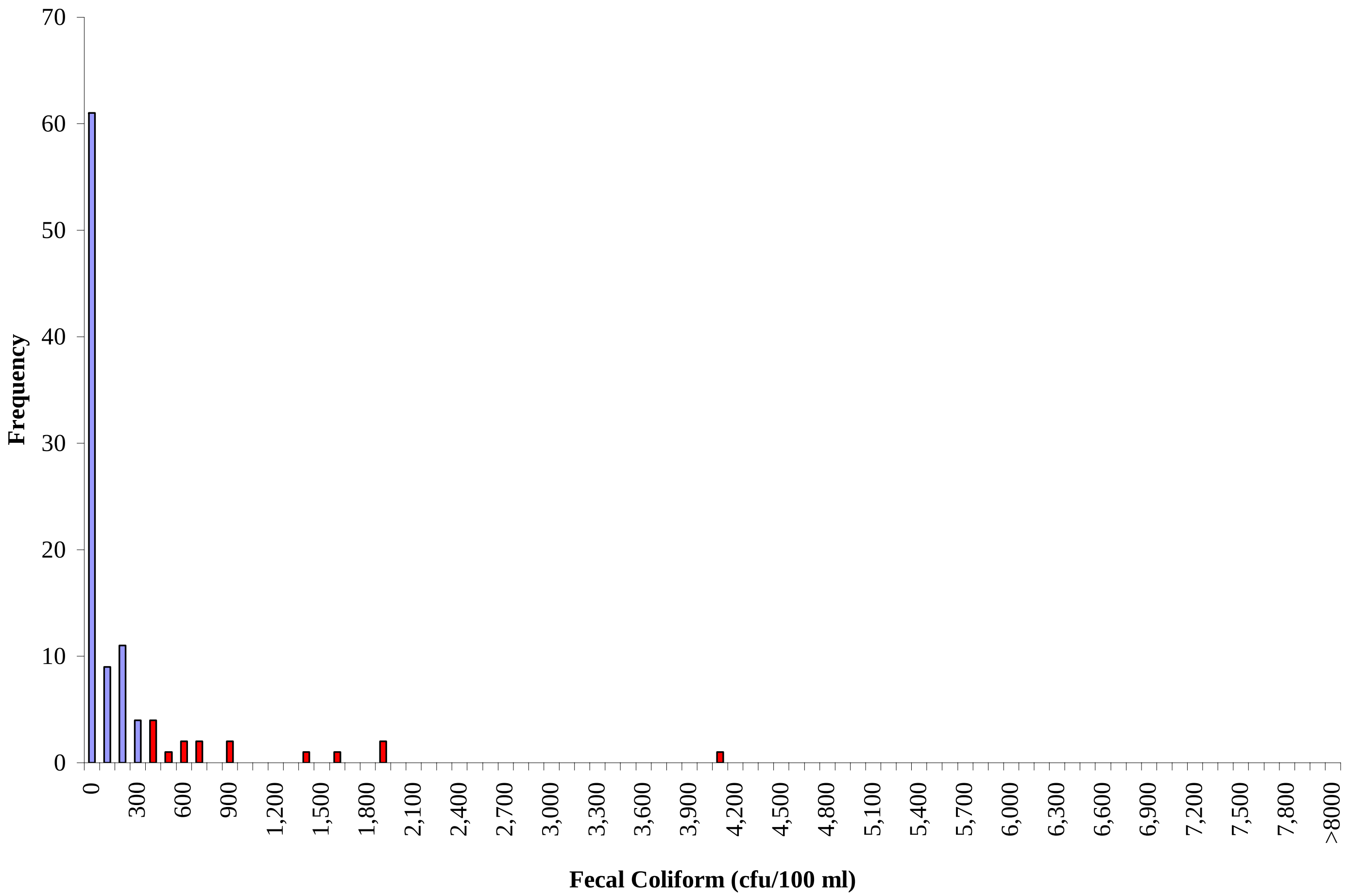

Figure A.5 **Frequency analysis of fecal coliform concentrations at station 5BWNC003.65 in the West Neck Creek (Middle) impairment for period June 1991 to March 2004.**

*Red indicates a value which violates the listing standard of 400 cfu/100 ml.

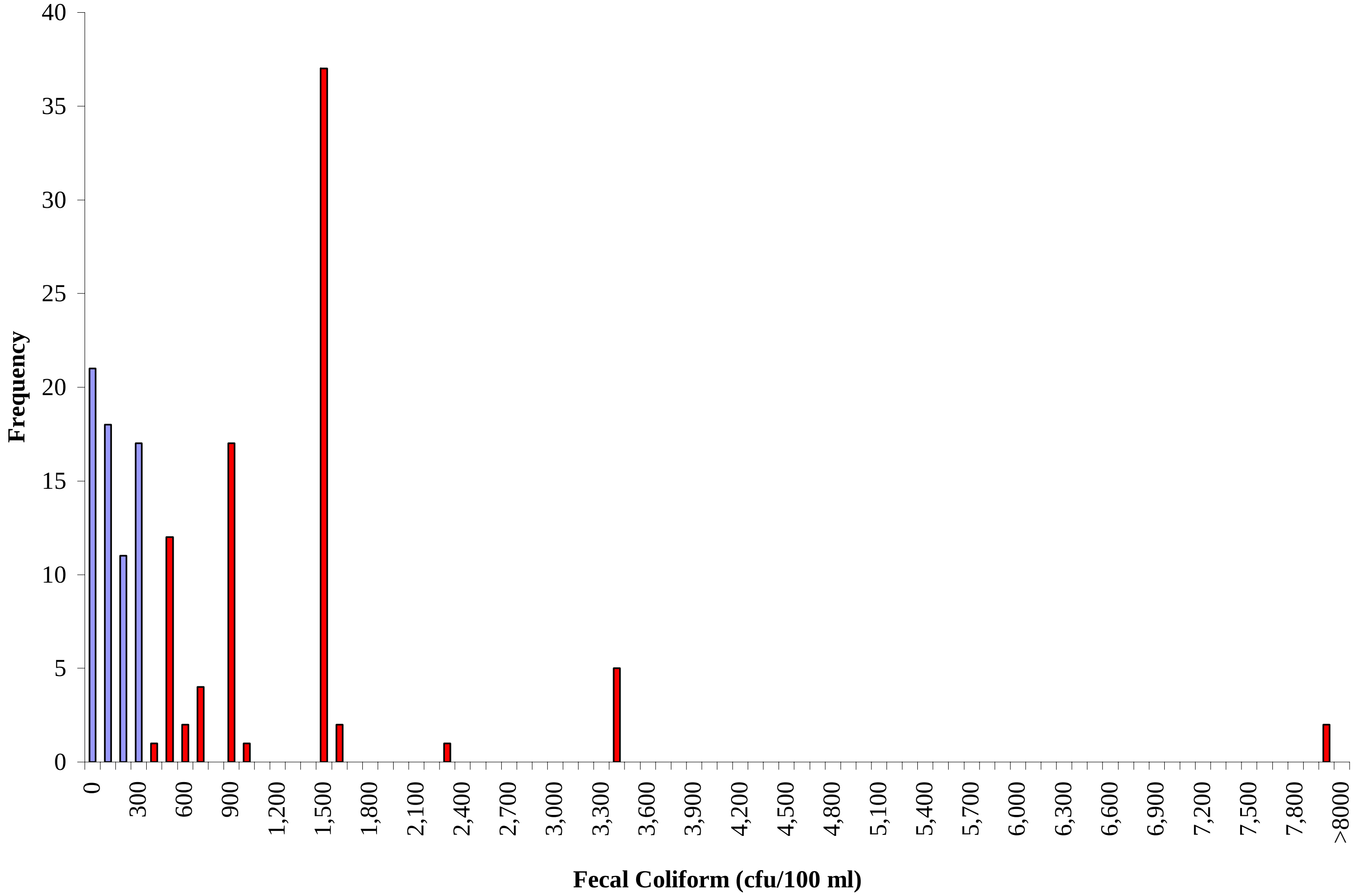

Figure A.6 Frequency analysis of fecal coliform concentrations at station 7LOB001.79 in the London Bridge Creek & Canal #2 impairment for period January 1990 to March 2004.

*Red indicates a value which violates the listing standard of 400 cfu/100 ml.

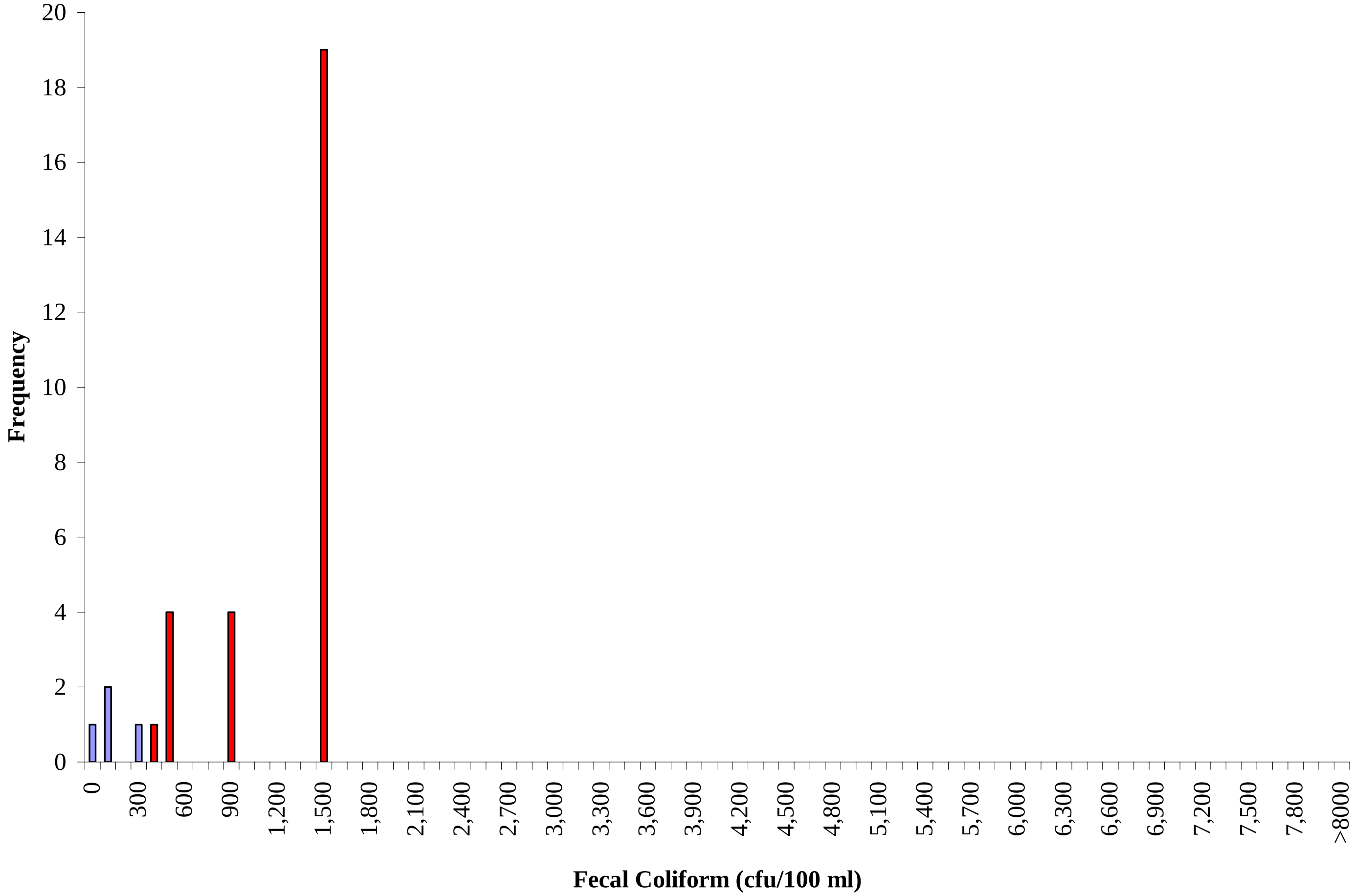

Figure A.7 **Frequency analysis of fecal coliform concentrations at station 7LOB003.70 in the London Bridge Creek & Canal #2 impairment for period December 1997 to August 2000.**

*Red indicates a value which violates the listing standard of 400 cfu/100 ml.

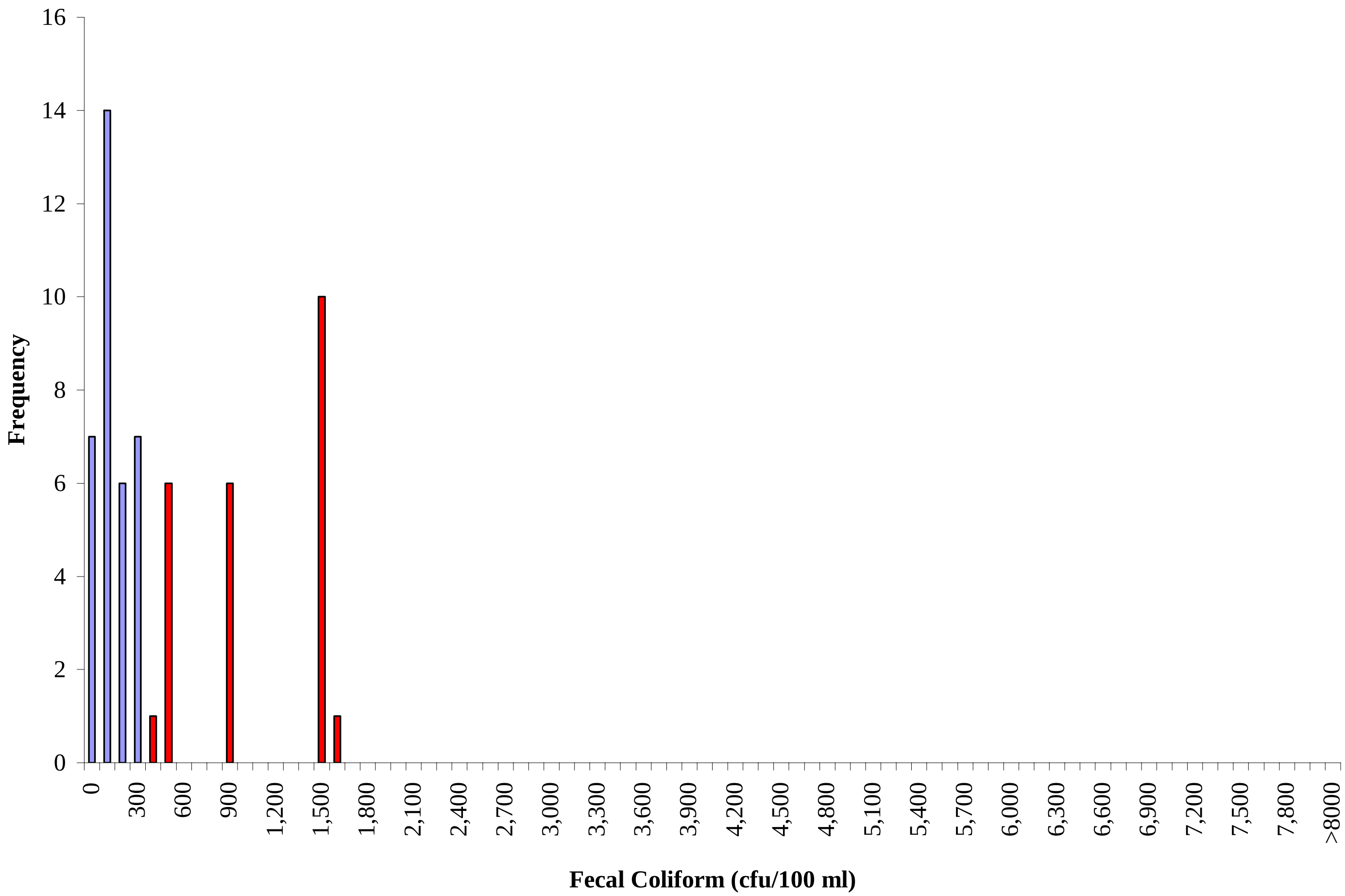

Figure A.8 Frequency analysis of fecal coliform concentrations at station 7XBO001.30 in the London Bridge Creek & Canal #2 impairment for period December 1997 to March 2004.

*Red indicates a value which violates the listing standard of 400 cfu/100 ml.

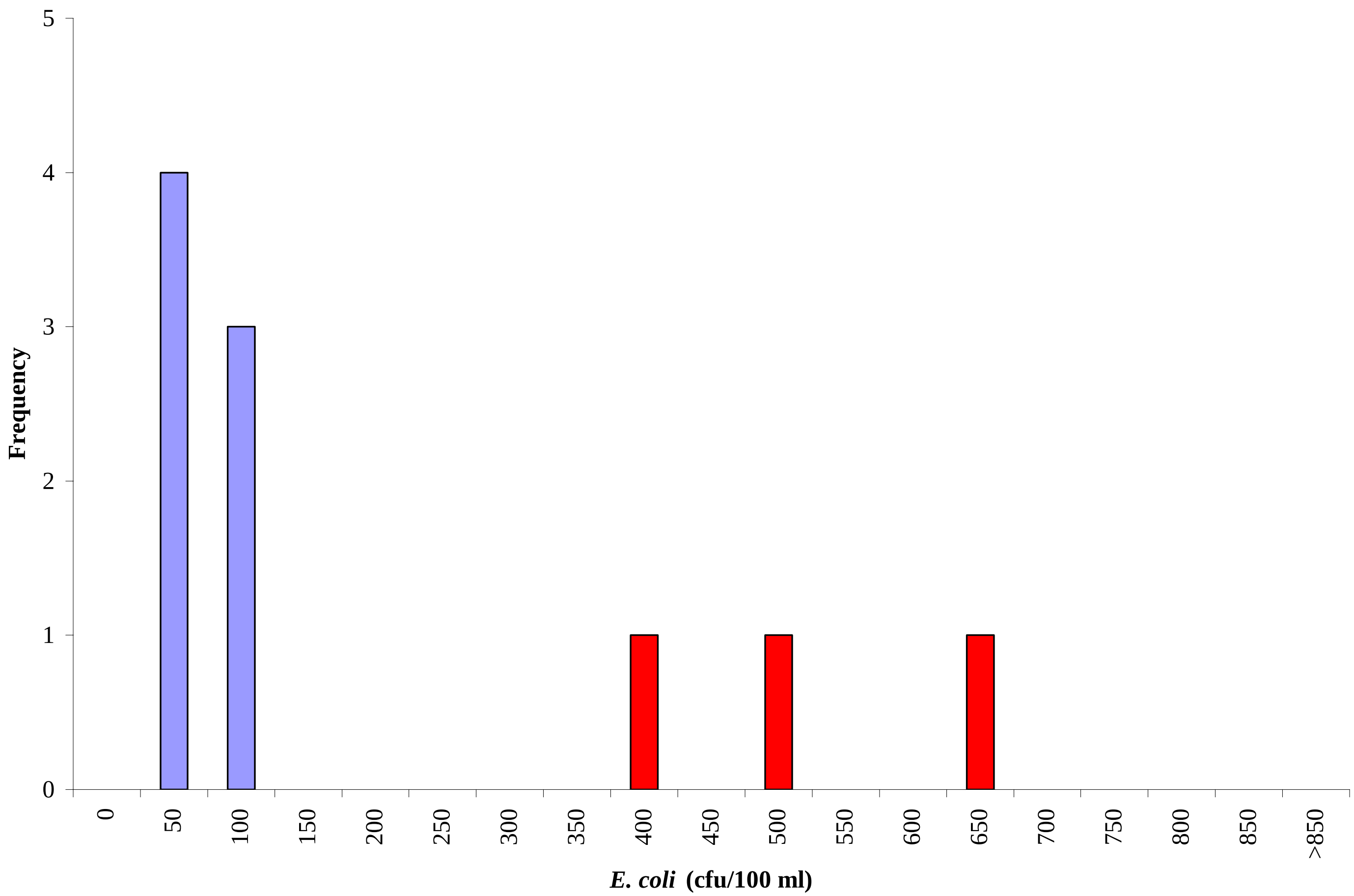

Figure A.9 Frequency analysis of *E.coli* concentrations at station 5BMLD001.92 in the Milldam Creek impairment for period July 2002 to March 2004.

*Red indicates a value which violates the listing standard of 235 cfu/100 ml.

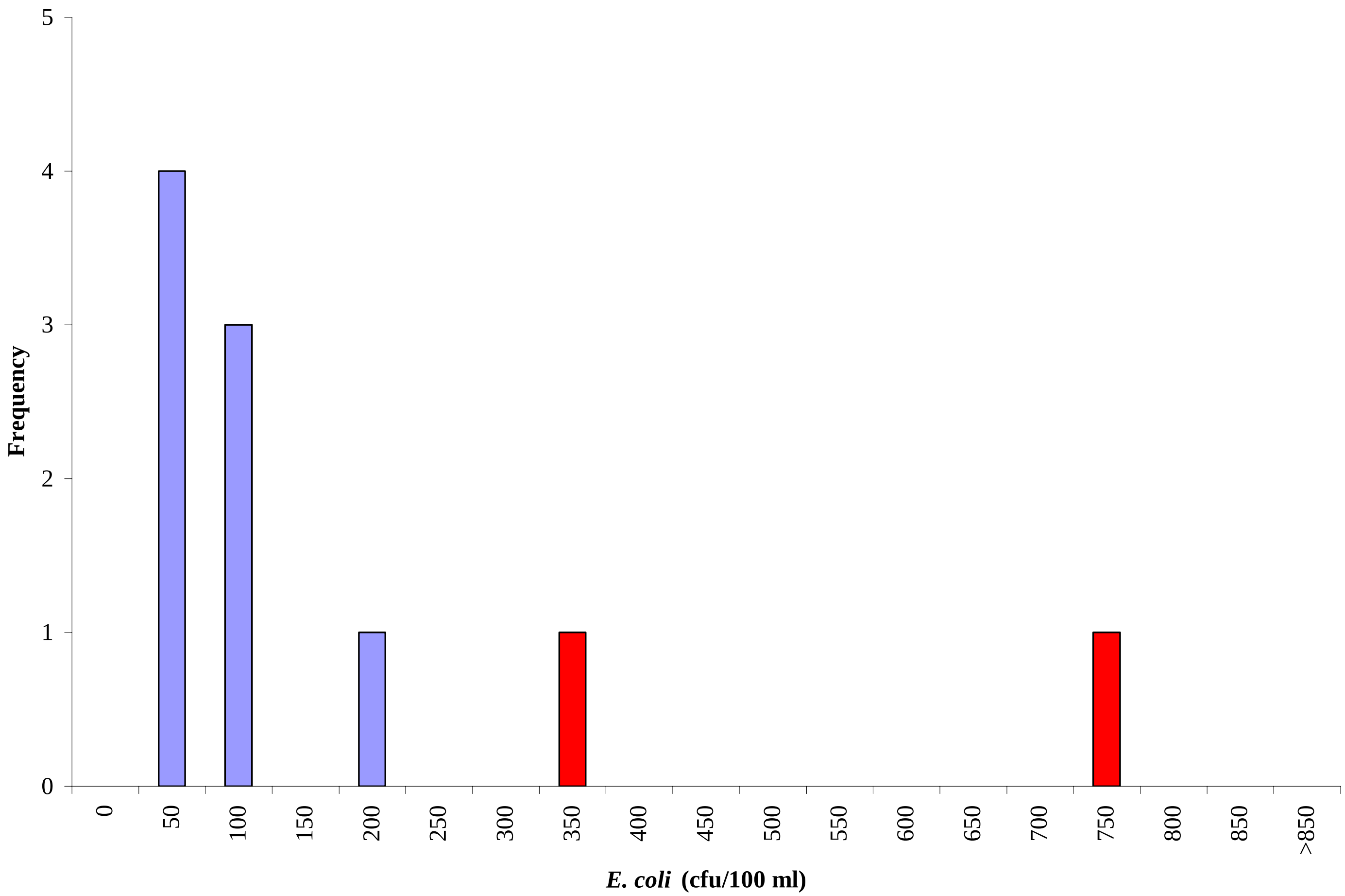

Figure A.10 Frequency analysis of *E.coli* concentrations at station 5BNWN000.00 in the Nawney Creek impairment for period July 2002 to March 2004.

*Red indicates a value which violates the listing standard of 235 cfu/100 ml.

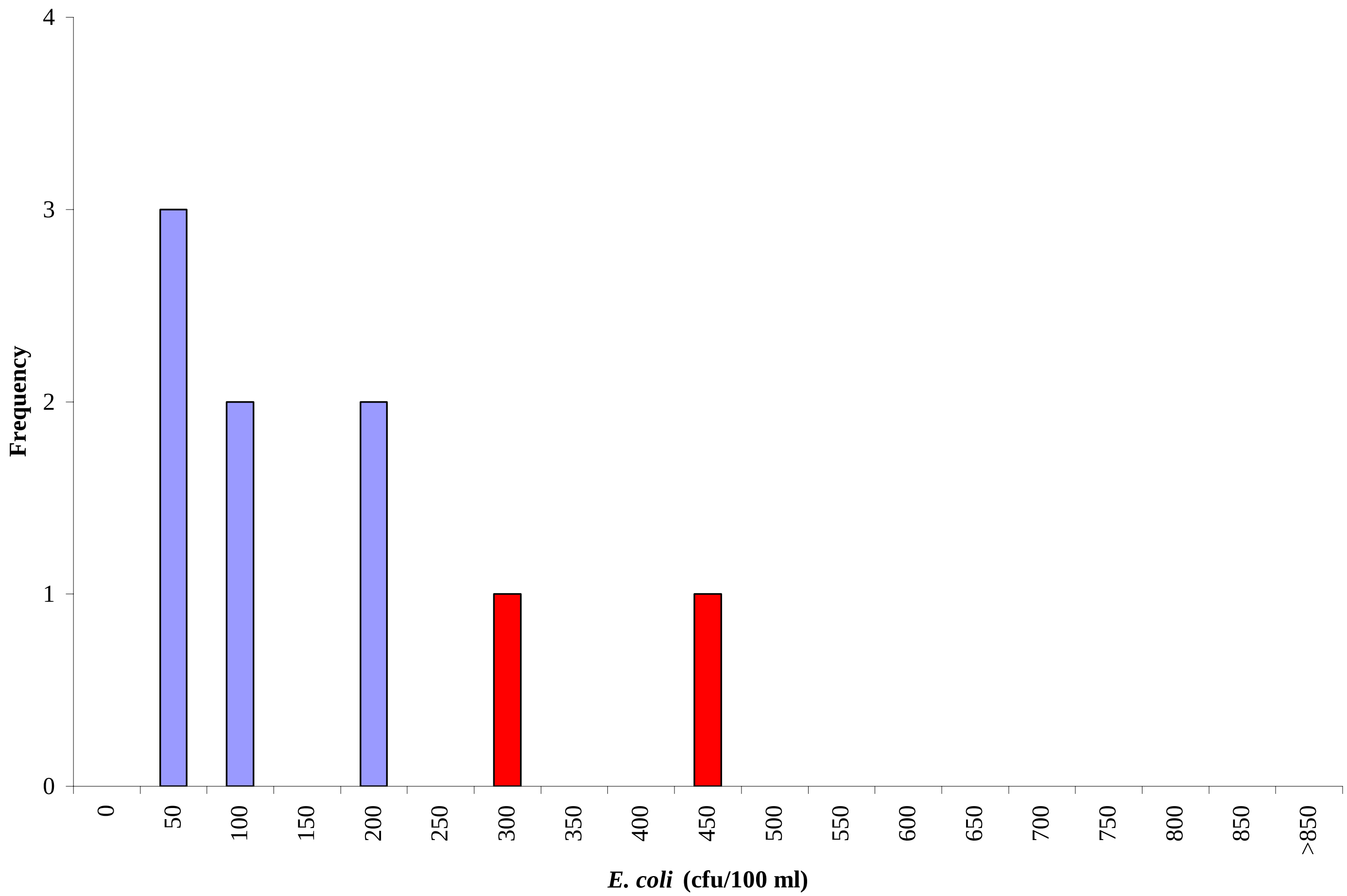

Figure A.11 Frequency analysis of *E.coli* concentrations at station 5BNWN001.84 in the Nawney Creek impairment for period July 2002 to March 2004.

*Red indicates a value which violates the listing standard of 235 cfu/100 ml.

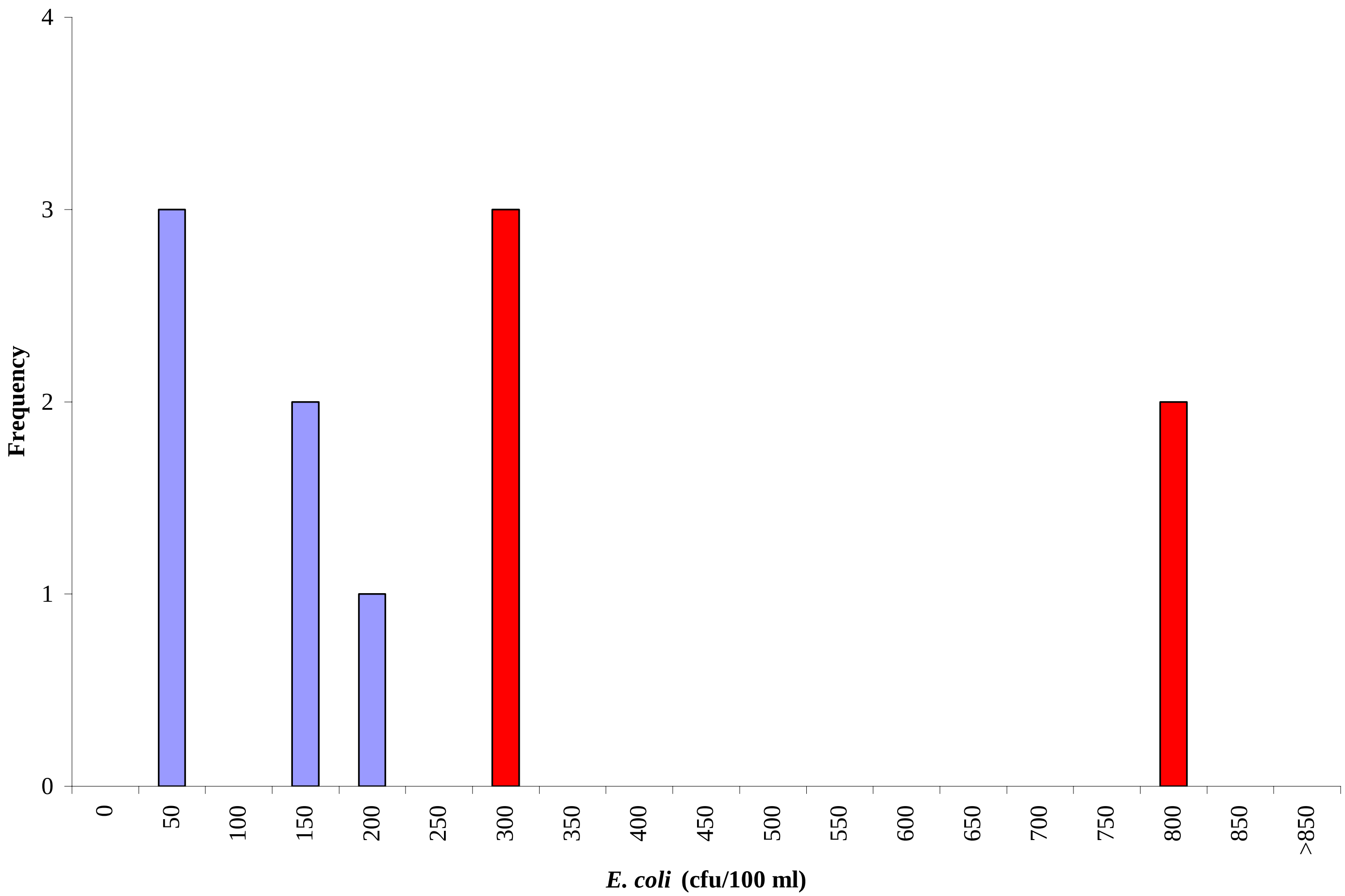

Figure A.12 Frequency analysis of *E.coli* concentrations at station 5BWNC010.02 in the West Neck Creek (Upper) impairment for period July 2003 to March 2004.

*Red indicates a value which violates the listing standard of 235 cfu/100 ml.

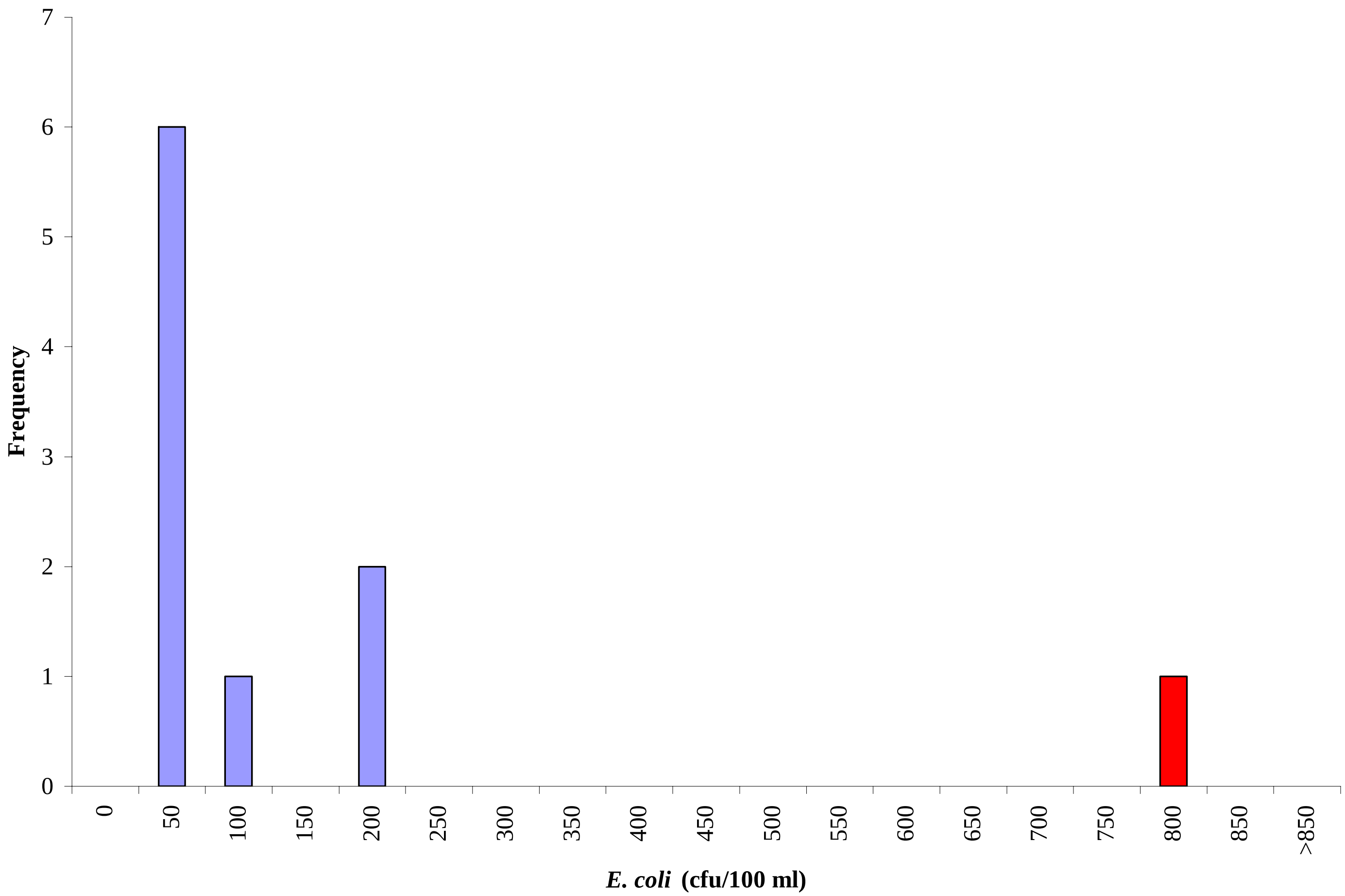

Figure A.13 Frequency analysis of *E.coli* concentrations at station 5BWNC003.65 in the West Neck Creek (Middle) impairment for period July 2002 to March 2004.

*Red indicates a value which violates the listing standard of 235 cfu/100 ml.

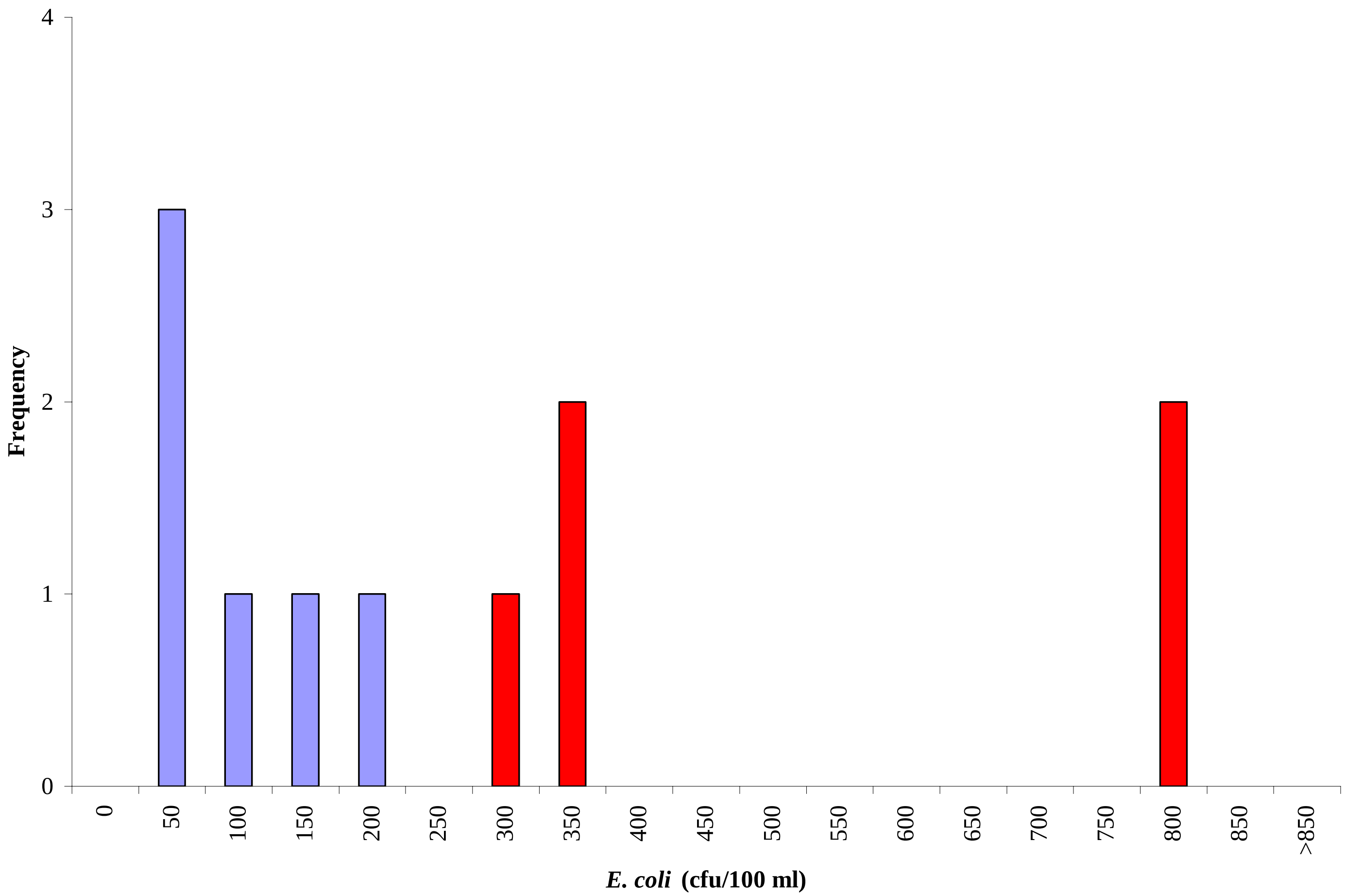

Figure A.14 Frequency analysis of *E.coli* concentrations at station 7LOB001.79 in the London Bridge Creek & Canal # 2 impairment for period July 2002 to March 2004.

*Red indicates a value which violates the listing standard of 235 cfu/100 ml.

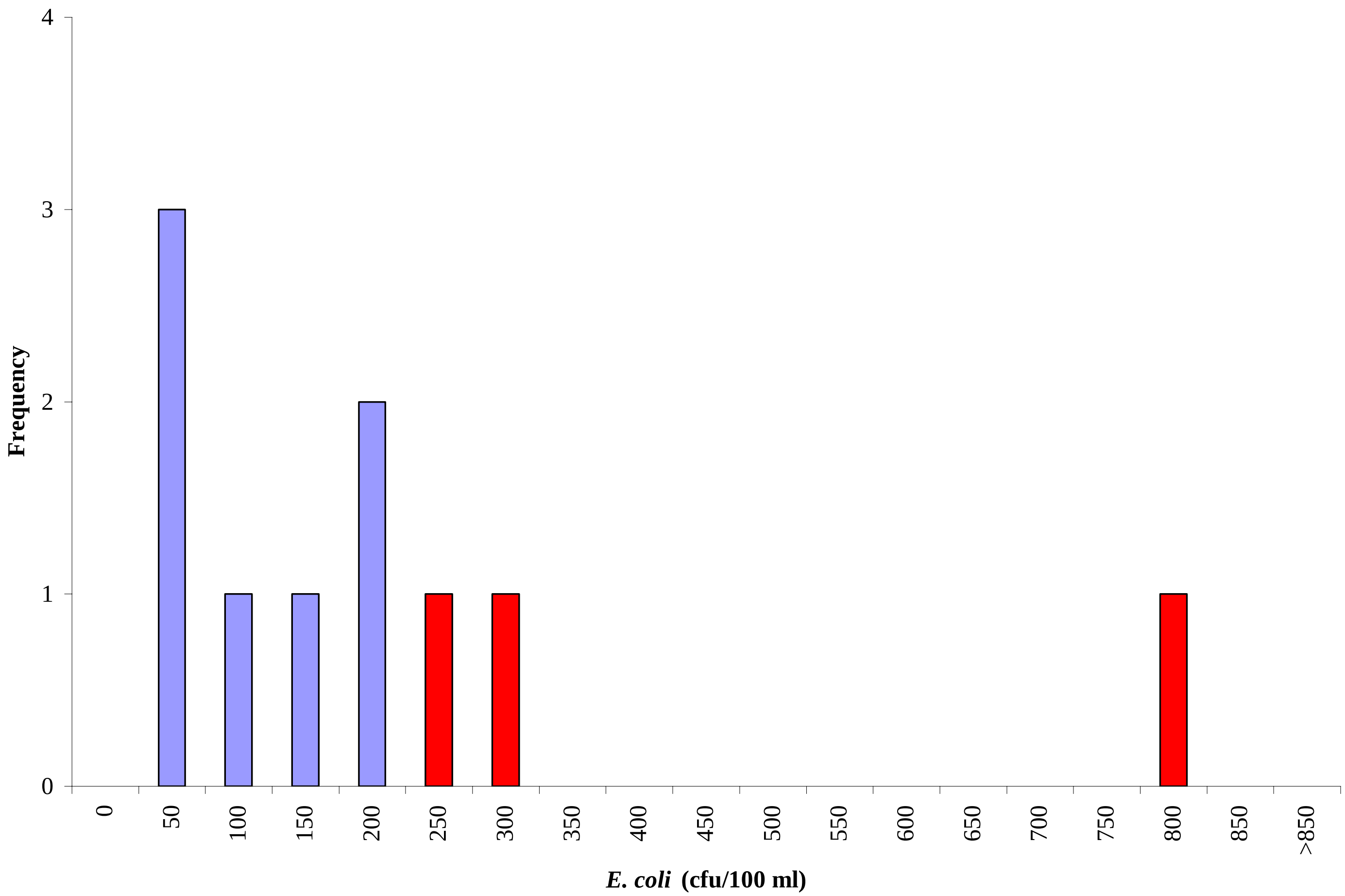

Figure A.15 Frequency analysis of *E.coli* concentrations at station 7LOB001.79 in the London Bridge Creek & Canal # 2 impairment for period July 2002 to March 2004.

*Red indicates a value which violates the listing standard of 235 cfu/100 ml.

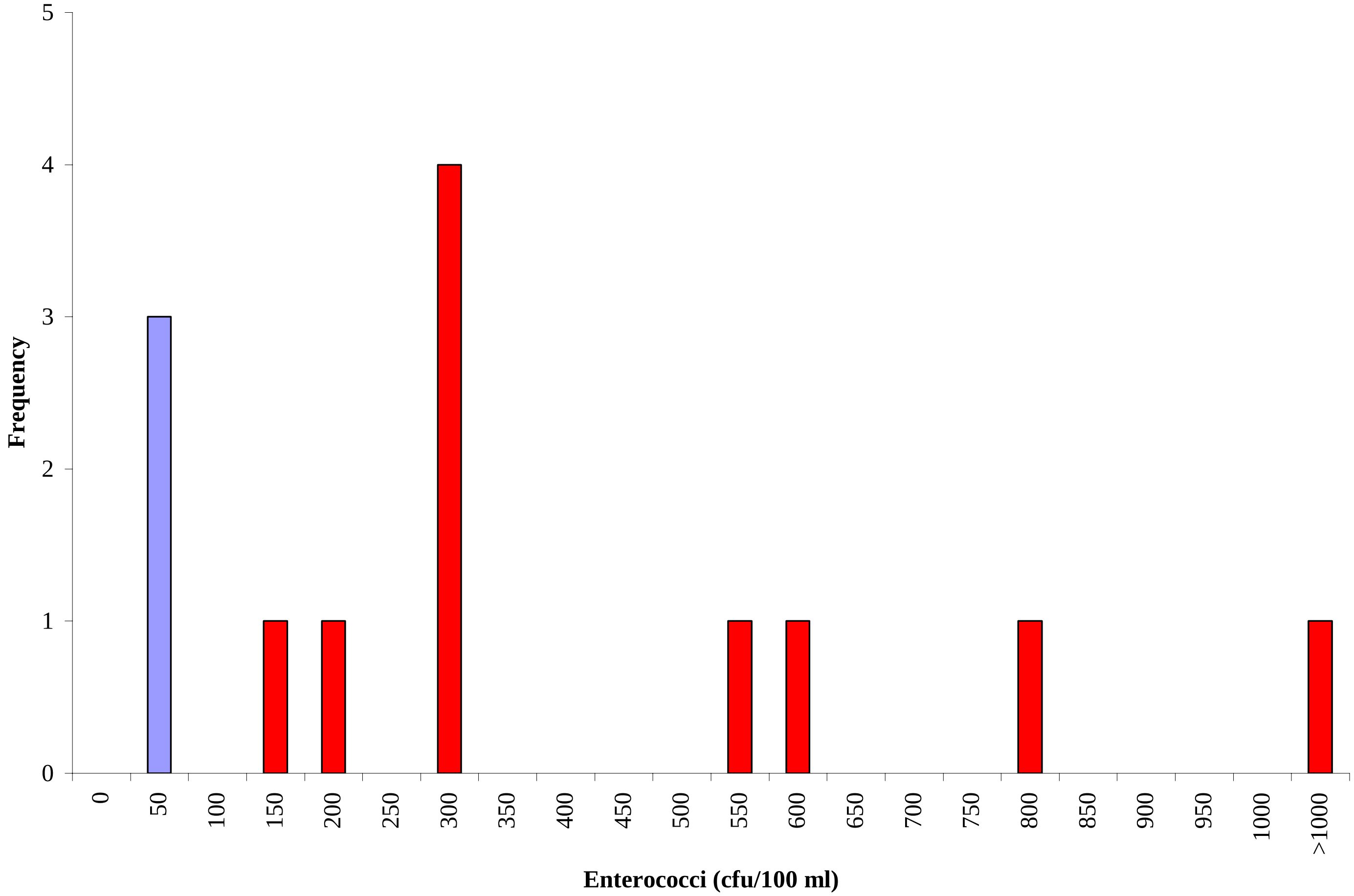

Figure A.16 Frequency analysis of *enterococci* concentrations at station 7LOB001.79 in the London Bridge Creek & Canal # 2 impairment for period July 2002 to August 2004.

*Red indicates a value which violates the listing standard of 104 cfu/100 ml.

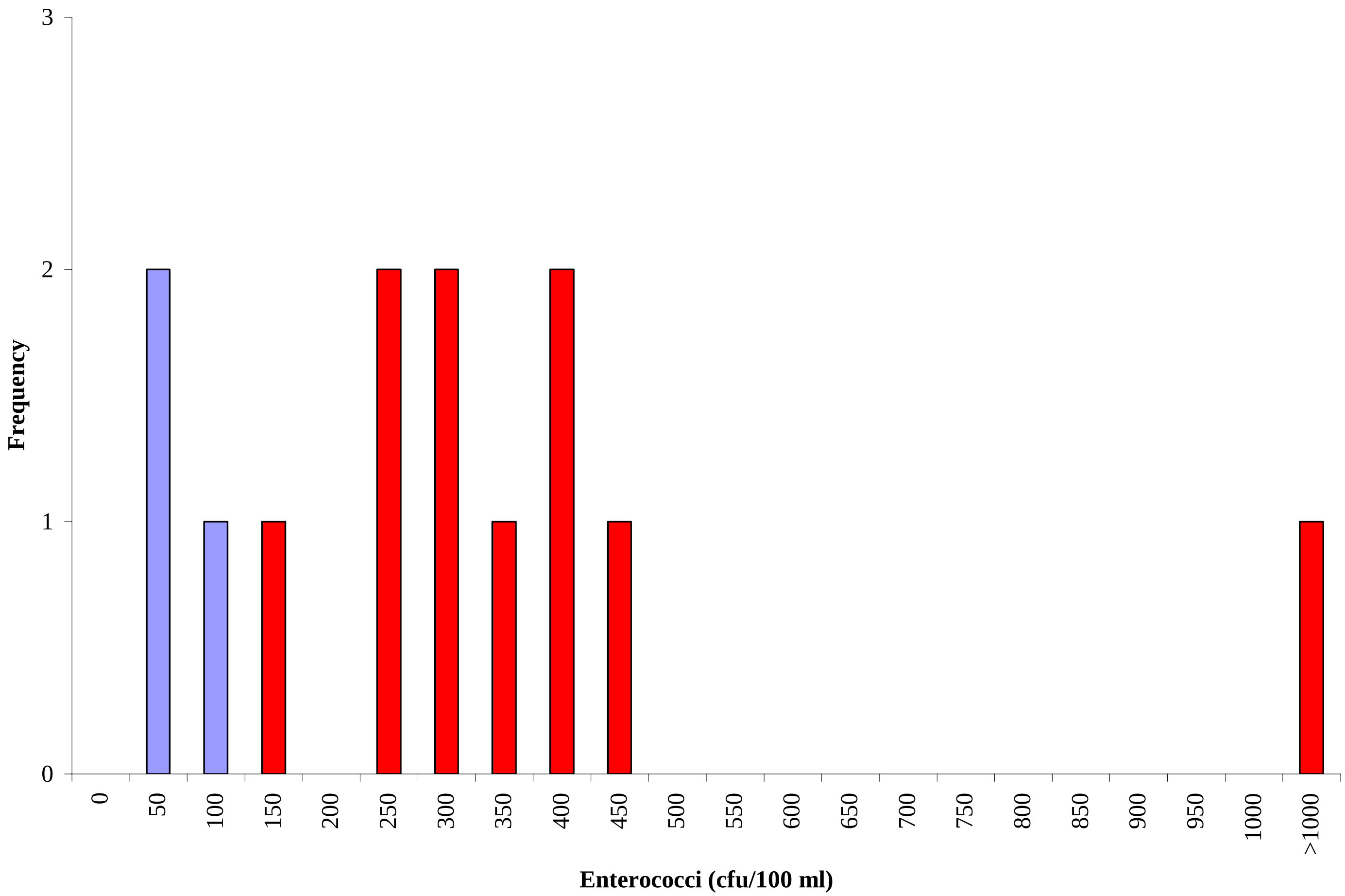

Figure A.17 Frequency analysis of *enterococci* concentrations at station 5BWNC010.02 in the West Neck Creek (Upper) impairment for period July 2002 to August 2004.

*Red indicates a value which violates the listing standard of 104 cfu/100 ml.

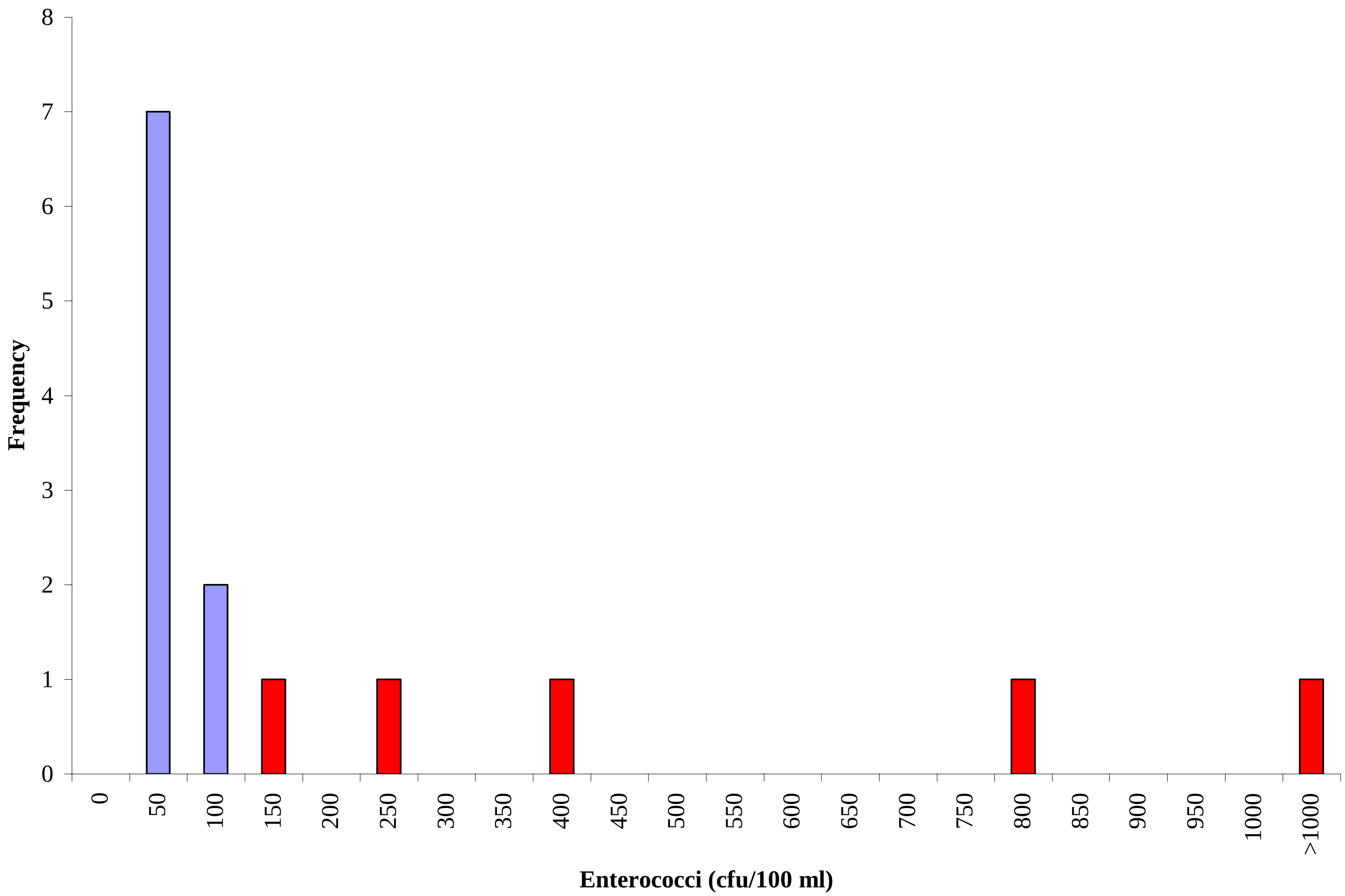

Figure A.18 Frequency analysis of *enterococci* concentrations at station 5BNWN000.00 in the Nawney Creek impairment for period July 2002 to September 2004.

*Red indicates a value which violates the listing standard of 104 cfu/100 ml.

APPENDIX B

FECAL COLIFORM LOADS IN EXISTING CONDITIONS

Table B.1 Current conditions of land applied fecal coliform load for London Bridge / Canal #2 by landuse (Subwatersheds 1, 2, 3, 4, 5, 6, 7, 8, 9).

Landuse	Barren	Commercial	Cropland	High Density Residential	Livestock Access	Low Density Residential	Pasture	Wetlands	Woodland
January	2.52E+12	1.13E+12	1.57E+12	3.04E+13	1.48E+11	2.67E+13	4.66E+12	2.43E+12	2.63E+12
February	2.28E+12	1.02E+12	1.42E+12	2.75E+13	1.34E+11	2.41E+13	4.21E+12	2.19E+12	2.38E+12
March	2.52E+12	1.13E+12	1.57E+12	3.04E+13	1.48E+11	2.67E+13	4.66E+12	2.43E+12	2.63E+12
April	2.44E+12	1.10E+12	1.52E+12	2.94E+13	1.43E+11	2.58E+13	4.51E+12	2.35E+12	2.55E+12
May	2.52E+12	1.13E+12	1.57E+12	3.04E+13	1.48E+11	2.66E+13	4.66E+12	2.43E+12	2.63E+12
June	2.44E+12	1.10E+12	1.52E+12	2.94E+13	1.43E+11	2.57E+13	4.51E+12	2.35E+12	2.55E+12
July	2.52E+12	1.13E+12	1.57E+12	3.04E+13	1.48E+11	2.66E+13	4.66E+12	2.43E+12	2.63E+12
August	2.52E+12	1.13E+12	1.57E+12	3.04E+13	1.48E+11	2.66E+13	4.66E+12	2.43E+12	2.63E+12
September	2.44E+12	1.10E+12	1.52E+12	2.94E+13	1.43E+11	2.57E+13	4.51E+12	2.35E+12	2.55E+12
October	2.52E+12	1.13E+12	1.57E+12	3.04E+13	1.48E+11	2.65E+13	4.66E+12	2.43E+12	2.63E+12
November	2.44E+12	1.10E+12	1.52E+12	2.94E+13	1.43E+11	2.57E+13	4.51E+12	2.35E+12	2.55E+12
December	2.52E+12	1.13E+12	1.57E+12	3.04E+13	1.48E+11	2.66E+13	4.66E+12	2.43E+12	2.63E+12
Annual Total Loads (cfu/yr)	2.97E+13	1.34E+13	1.85E+13	3.58E+14	1.74E+12	3.13E+14	5.49E+13	2.86E+13	3.10E+13

Table B.2 Monthly, directly deposited fecal coliform loads in each reach of the London Bridge / Canal #2 (Reaches 1, 2, 3, 4, 5, 6, 7, 8, 9).

Reach ID	Source Type	January	February	March	April	May	June
1	Human/Pet	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	1.10E+10	9.93E+09	1.10E+10	1.06E+10	1.10E+10	1.06E+10
2	Human/Pet	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	2.15E+10	1.94E+10	2.15E+10	2.08E+10	2.15E+10	2.08E+10
3	Human/Pet	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	6.14E+10	5.54E+10	6.14E+10	5.94E+10	6.14E+10	5.94E+10
4	Human/Pet	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	4.65E+10	4.20E+10	4.65E+10	4.50E+10	4.65E+10	4.50E+10
5	Human/Pet	5.94E+08	5.37E+08	5.94E+08	5.75E+08	5.94E+08	5.75E+08
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	5.79E+10	5.23E+10	5.79E+10	5.60E+10	5.79E+10	5.60E+10
6	Human/Pet	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	2.00E+10	1.81E+10	2.00E+10	1.94E+10	2.00E+10	1.94E+10
7	Human/Pet	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	1.05E+11	9.45E+10	1.05E+11	1.01E+11	1.05E+11	1.01E+11
8	Human/Pet	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	2.11E+10	1.91E+10	2.11E+10	2.04E+10	2.11E+10	2.04E+10
9	Human/Pet	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	7.54E+10	6.81E+10	7.54E+10	7.30E+10	7.54E+10	7.30E+10

Table B.2 Monthly, directly deposited fecal coliform loads in each reach of the London Bridge / Canal #2 (Reaches 1, 2, 3, 4, 5, 6, 7, 8, 9), (cont.).

Reach ID	Source Type	July	August	September	October	November	December
1	Human/Pet	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	1.10E+10	1.10E+10	1.06E+10	1.10E+10	1.06E+10	1.10E+10
2	Human/Pet	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	2.15E+10	2.15E+10	2.08E+10	2.15E+10	2.08E+10	2.15E+10
3	Human/Pet	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	6.14E+10	6.14E+10	5.94E+10	6.14E+10	5.94E+10	6.14E+10
4	Human/Pet	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	4.65E+10	4.65E+10	4.50E+10	4.65E+10	4.50E+10	4.65E+10
5	Human/Pet	5.94E+08	5.94E+08	5.75E+08	5.94E+08	5.75E+08	5.94E+08
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	5.79E+10	5.79E+10	5.60E+10	5.79E+10	5.60E+10	5.79E+10
6	Human/Pet	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	2.00E+10	2.00E+10	1.94E+10	2.00E+10	1.94E+10	2.00E+10
7	Human/Pet	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	1.05E+11	1.05E+11	1.01E+11	1.05E+11	1.01E+11	1.05E+11
8	Human/Pet	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	2.11E+10	2.11E+10	2.04E+10	2.11E+10	2.04E+10	2.11E+10
9	Human/Pet	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	7.54E+10	7.54E+10	7.30E+10	7.54E+10	7.30E+10	7.54E+10

Table B.3 Existing annual loads from land-based sources for the London Bridge / Canal #2 (Subwatersheds 1, 2, 3, 4, 5, 6, 7, 8, 9).

Source	Barren	Commercial	Cropland	High Density Residential	Livestock Access	Low Density Residential	Pasture	Water	Wetlands	Woodland
beaver	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.86E+09	0.00E+00	0.00E+00
beef	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
cats high residential	0.00E+00	0.00E+00	0.00E+00	8.57E+08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
cats low residential	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.27E+08	0.00E+00	0.00E+00	0.00E+00	0.00E+00
deer	7.98E+11	7.57E+10	7.23E+11	6.82E+10	7.07E+10	1.72E+12	5.55E+11	0.00E+00	2.67E+12	2.21E+12
dogs high residential	0.00E+00	0.00E+00	0.00E+00	3.32E+14	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
dogs low residential	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.43E+14	0.00E+00	0.00E+00	0.00E+00	0.00E+00
duck	6.64E+08	2.10E+08	4.43E+08	4.97E+08	9.20E+07	9.21E+08	1.44E+08	0.00E+00	7.42E+08	4.89E+08
goose	4.31E+11	1.36E+11	2.88E+11	3.22E+11	5.97E+10	5.97E+11	9.34E+10	0.00E+00	4.81E+11	3.17E+11
gull	1.15E+13	4.83E+12	7.26E+12	1.01E+13	9.07E+11	2.21E+13	3.09E+12	0.00E+00	1.00E+13	9.82E+12
hog	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
horse	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.68E+13	0.00E+00	0.00E+00	0.00E+00
muskrat	5.60E+12	2.48E+12	2.98E+12	4.52E+12	1.46E+11	1.24E+13	4.97E+11	0.00E+00	6.78E+12	6.97E+12
raccoon	1.13E+13	5.83E+12	7.25E+12	1.15E+13	5.58E+11	2.95E+13	3.78E+12	0.00E+00	8.65E+12	1.17E+13
septic failure density	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.38E+12	0.00E+00	0.00E+00	0.00E+00	0.00E+00
sheep	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.42E+10	0.00E+00	0.00E+00	0.00E+00
straightpipe density	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E+09	0.00E+00	0.00E+00

Table B.4 Existing annual loads from direct-deposition sources for the London Bridge / Canal #2 (Reaches 1, 2, 3, 4, 5, 6, 7, 8, 9).

Source	Annual Total Loads (cfu/yr)
beaver	3.86E+09
beef	0.00E+00
deer	4.52E+09
duck	1.99E+08
goose	8.48E+10
gull	2.27E+12
hog	0.00E+00
muskrat	2.34E+12
raccoon	2.32E+11
straightpipe_density	7.00E+09

Table B.5 Current conditions of land applied fecal coliform load for Milldam by landuse (Subwatersheds 33, 34, 35, 36, 37, 38, 39, 40, 41, 42).

Landuse	Commercial	Cropland	Livestock Access	Low_Density Residential	Pasture	Wetlands	Woodland
January	1.13E+09	2.89E+12	8.05E+10	5.42E+11	5.72E+11	8.54E+12	6.94E+11
February	1.02E+09	2.61E+12	7.27E+10	4.77E+11	5.17E+11	7.71E+12	6.27E+11
March	1.13E+09	2.89E+12	8.05E+10	5.00E+11	5.72E+11	8.54E+12	6.94E+11
April	1.09E+09	2.80E+12	7.79E+10	4.71E+11	5.54E+11	8.26E+12	6.72E+11
May	1.13E+09	2.89E+12	8.05E+10	4.73E+11	5.72E+11	8.54E+12	6.94E+11
June	1.09E+09	2.80E+12	7.79E+10	4.44E+11	5.54E+11	8.26E+12	6.72E+11
July	1.13E+09	2.89E+12	8.05E+10	4.31E+11	5.72E+11	8.54E+12	6.94E+11
August	1.13E+09	2.89E+12	8.05E+10	4.31E+11	5.72E+11	8.54E+12	6.94E+11
September	1.09E+09	2.80E+12	7.79E+10	4.17E+11	5.54E+11	8.26E+12	6.72E+11
October	1.13E+09	2.89E+12	8.05E+10	4.17E+11	5.72E+11	8.54E+12	6.94E+11
November	1.09E+09	2.80E+12	7.79E+10	4.17E+11	5.54E+11	8.26E+12	6.72E+11
December	1.13E+09	2.89E+12	8.05E+10	4.87E+11	5.72E+11	8.54E+12	6.94E+11
Annual Total Loads (cfu/yr)	1.33E+10	3.41E+13	9.48E+11	5.51E+12	6.74E+12	1.01E+14	8.17E+12

Table B.6 Monthly, directly deposited fecal coliform loads in each reach of the Milldam (Reaches 33, 34, 35, 36, 37, 38, 39, 40, 41, 42).

Reach ID	Source Type	January	February	March	April	May	June
33	Human/Pet	4.59E+10	4.14E+10	4.59E+10	4.44E+10	4.59E+10	4.44E+10
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	4.81E+10	4.35E+10	4.81E+10	4.66E+10	4.81E+10	4.66E+10
34	Human/Pet	7.39E+10	6.67E+10	7.39E+10	7.15E+10	7.39E+10	7.15E+10
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	1.20E+10	1.09E+10	1.20E+10	1.17E+10	1.20E+10	1.17E+10
35	Human/Pet	6.49E+10	5.86E+10	6.49E+10	6.28E+10	6.49E+10	6.28E+10
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	3.75E+10	3.39E+10	3.75E+10	3.63E+10	3.75E+10	3.63E+10
36	Human/Pet	3.91E+11	3.54E+11	3.91E+11	3.79E+11	3.91E+11	3.79E+11
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	2.72E+10	2.45E+10	2.72E+10	2.63E+10	2.72E+10	2.63E+10
37	Human/Pet	4.52E+11	4.09E+11	4.52E+11	4.38E+11	4.52E+11	4.38E+11
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	1.32E+10	1.19E+10	1.32E+10	1.28E+10	1.32E+10	1.28E+10
38	Human/Pet	2.97E+10	2.68E+10	2.97E+10	2.87E+10	2.97E+10	2.87E+10
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	1.21E+10	1.09E+10	1.21E+10	1.17E+10	1.21E+10	1.17E+10
39	Human/Pet	3.11E+10	2.81E+10	3.11E+10	3.01E+10	3.11E+10	3.01E+10
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	8.56E+09	7.73E+09	8.56E+09	8.28E+09	8.56E+09	8.28E+09
40	Human/Pet	4.37E+10	3.95E+10	4.37E+10	4.23E+10	4.37E+10	4.23E+10
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	2.16E+10	1.95E+10	2.16E+10	2.09E+10	2.16E+10	2.09E+10
41	Human/Pet	8.75E+10	7.90E+10	8.75E+10	8.46E+10	8.75E+10	8.46E+10
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	1.20E+10	1.09E+10	1.20E+10	1.16E+10	1.20E+10	1.16E+10
42	Human/Pet	6.40E+10	5.78E+10	6.40E+10	6.19E+10	6.40E+10	6.19E+10
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	4.85E+10	4.38E+10	4.85E+10	4.70E+10	4.85E+10	4.70E+10

Table B.6 Table B.42 Monthly, directly deposited fecal coliform loads in each reach of the Milldam (Reaches 33, 34, 35, 36, 37, 38, 39, 40, 41, 42), (cont.).

Reach ID	Source Type	July	August	September	October	November	December
33	Human/Pet	4.59E+10	4.59E+10	4.44E+10	4.59E+10	4.44E+10	4.59E+10
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	4.81E+10	4.81E+10	4.66E+10	4.81E+10	4.66E+10	4.81E+10
34	Human/Pet	7.39E+10	7.39E+10	7.15E+10	7.39E+10	7.15E+10	7.39E+10
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	1.20E+10	1.20E+10	1.17E+10	1.20E+10	1.17E+10	1.20E+10
35	Human/Pet	6.49E+10	6.49E+10	6.28E+10	6.49E+10	6.28E+10	6.49E+10
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	3.75E+10	3.75E+10	3.63E+10	3.75E+10	3.63E+10	3.75E+10
36	Human/Pet	3.91E+11	3.91E+11	3.79E+11	3.91E+11	3.79E+11	3.91E+11
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	2.72E+10	2.72E+10	2.63E+10	2.72E+10	2.63E+10	2.72E+10
37	Human/Pet	4.52E+11	4.52E+11	4.38E+11	4.52E+11	4.38E+11	4.52E+11
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	1.32E+10	1.32E+10	1.28E+10	1.32E+10	1.28E+10	1.32E+10
38	Human/Pet	2.97E+10	2.97E+10	2.87E+10	2.97E+10	2.87E+10	2.97E+10
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	1.21E+10	1.21E+10	1.17E+10	1.21E+10	1.17E+10	1.21E+10
39	Human/Pet	3.11E+10	3.11E+10	3.01E+10	3.11E+10	3.01E+10	3.11E+10
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	8.56E+09	8.56E+09	8.28E+09	8.56E+09	8.28E+09	8.56E+09
40	Human/Pet	4.37E+10	4.37E+10	4.23E+10	4.37E+10	4.23E+10	4.37E+10
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	2.16E+10	2.16E+10	2.09E+10	2.16E+10	2.09E+10	2.16E+10
41	Human/Pet	8.75E+10	8.75E+10	8.46E+10	8.75E+10	8.46E+10	8.75E+10
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	1.20E+10	1.20E+10	1.16E+10	1.20E+10	1.16E+10	1.20E+10
42	Human/Pet	6.40E+10	6.40E+10	6.19E+10	6.40E+10	6.19E+10	6.40E+10
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	4.85E+10	4.85E+10	4.70E+10	4.85E+10	4.70E+10	4.85E+10

Table B.7 Existing annual loads from land-based sources for the Milldam (Subwatersheds 33, 34, 35, 36, 37, 38, 39, 40, 41, 42).

Source	Barren	Commercial	Cropland	High Density Residential	Livestock Access	Low Density Residential	Pasture	Water	Wetlands	Woodland
beaver	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.08E+09	0.00E+00	0.00E+00
beef	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
cats low residential	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.26E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
deer	0.00E+00	1.12E+08	9.33E+11	0.00E+00	1.40E+10	0.00E+00	7.81E+10	0.00E+00	2.23E+12	2.06E+11
dogs low residential	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.42E+12	0.00E+00	0.00E+00	0.00E+00	0.00E+00
duck	0.00E+00	2.41E+05	9.16E+08	0.00E+00	4.38E+07	1.21E+06	5.26E+07	0.00E+00	6.41E+09	1.59E+08
goose	0.00E+00	1.57E+08	5.94E+11	0.00E+00	2.84E+10	7.84E+08	3.41E+10	0.00E+00	4.16E+12	1.03E+11
gull	0.00E+00	2.49E+09	1.48E+13	0.00E+00	4.11E+11	1.11E+10	1.07E+12	0.00E+00	5.75E+13	2.82E+12
hog	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
horse	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.97E+12	0.00E+00	0.00E+00	0.00E+00
muskrat	0.00E+00	5.49E+09	4.36E+12	0.00E+00	2.52E+11	5.50E+09	4.47E+11	0.00E+00	2.98E+12	2.20E+12
raccoon	0.00E+00	5.06E+09	1.33E+13	0.00E+00	2.42E+11	1.01E+10	1.14E+12	0.00E+00	3.36E+13	2.84E+12
septic failure density	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.06E+12	0.00E+00	0.00E+00	0.00E+00	0.00E+00
sheep	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
straightpipe density	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.51E+13	0.00E+00	0.00E+00

Table B.8 Existing annual loads from direct-deposition sources for the Milldam (Reaches 33, 34, 35, 36, 37, 38, 39, 40, 41, 42).

Source	Annual Total Loads (cfu/yr)
beaver	3.08E+09
beef	0.00E+00
deer	1.76E+09
duck	3.14E+08
goose	1.34E+11
gull	2.07E+12
hog	0.00E+00
muskrat	4.91E+11
raccoon	1.31E+11
Straightpipe_Density	1.51E+13

Table B.9 Current conditions of land applied fecal coliform load for Nawney by landuse (Subwatersheds 29, 30, 31, 32).

Landuse	Commercial	Cropland	High Density Residential	Livestock Access	Low Density Residential	Pasture	Wetlands	Woodland
January	1.47E+11	4.24E+13	6.89E+11	4.23E+11	2.27E+12	3.49E+12	5.75E+12	8.71E+11
February	1.33E+11	4.71E+13	6.22E+11	3.82E+11	1.99E+12	3.15E+12	5.19E+12	7.87E+11
March	1.47E+11	3.88E+14	6.89E+11	4.23E+11	2.08E+12	3.49E+12	5.75E+12	8.71E+11
April	1.42E+11	3.88E+14	6.66E+11	4.09E+11	1.95E+12	3.38E+12	5.56E+12	8.43E+11
May	1.47E+11	3.88E+14	6.89E+11	4.23E+11	1.95E+12	3.49E+12	5.75E+12	8.71E+11
June	1.42E+11	8.63E+12	6.66E+11	4.09E+11	1.82E+12	4.24E+13	5.56E+12	8.43E+11
July	1.47E+11	8.92E+12	6.89E+11	4.23E+11	1.76E+12	4.25E+13	5.75E+12	8.71E+11
August	1.47E+11	8.92E+12	6.89E+11	4.23E+11	1.76E+12	4.25E+13	5.75E+12	8.71E+11
September	1.42E+11	1.20E+14	6.66E+11	4.09E+11	1.70E+12	3.38E+12	5.56E+12	8.43E+11
October	1.47E+11	3.88E+14	6.89E+11	4.23E+11	1.69E+12	3.49E+12	5.75E+12	8.71E+11
November	1.42E+11	3.88E+14	6.66E+11	4.09E+11	1.70E+12	3.38E+12	5.56E+12	8.43E+11
December	1.47E+11	4.24E+13	6.89E+11	4.23E+11	2.01E+12	3.49E+12	5.75E+12	8.71E+11
Annual Total Loads (cfu/yr)	1.73E+12	2.22E+15	8.11E+12	4.98E+12	2.27E+13	1.58E+14	6.77E+13	1.03E+13

Table B.10 Monthly, directly deposited fecal coliform loads in each reach of the Nawney (Reaches 29, 30, 31, 32).

Reach ID	Source Type	January	February	March	April	May	June
29	Human/Pet	3.66E+11	3.30E+11	3.66E+11	3.54E+11	3.66E+11	3.54E+11
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	1.32E+11	1.19E+11	1.32E+11	1.28E+11	1.32E+11	1.28E+11
30	Human/Pet	1.96E+11	1.77E+11	1.96E+11	1.90E+11	1.96E+11	1.90E+11
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	7.79E+10	7.04E+10	7.79E+10	7.54E+10	7.79E+10	7.54E+10
31	Human/Pet	2.72E+11	2.46E+11	2.72E+11	2.63E+11	2.72E+11	2.63E+11
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	9.47E+10	8.55E+10	9.47E+10	9.17E+10	9.47E+10	9.17E+10
32	Human/Pet	1.75E+11	1.58E+11	1.75E+11	1.69E+11	1.75E+11	1.69E+11
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	3.79E+10	3.43E+10	3.79E+10	3.67E+10	3.79E+10	3.67E+10
Reach ID	**Source Type**	**July**	**August**	**September**	**October**	**November**	**December**
29	Human/Pet	3.66E+11	3.66E+11	3.54E+11	3.66E+11	3.54E+11	3.66E+11
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	1.32E+11	1.32E+11	1.28E+11	1.32E+11	1.28E+11	1.32E+11
30	Human/Pet	1.96E+11	1.96E+11	1.90E+11	1.96E+11	1.90E+11	1.96E+11
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	7.79E+10	7.79E+10	7.54E+10	7.79E+10	7.54E+10	7.79E+10
31	Human/Pet	2.72E+11	2.72E+11	2.63E+11	2.72E+11	2.63E+11	2.72E+11
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	9.47E+10	9.47E+10	9.17E+10	9.47E+10	9.17E+10	9.47E+10
32	Human/Pet	1.75E+11	1.75E+11	1.69E+11	1.75E+11	1.69E+11	1.75E+11
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	3.79E+10	3.79E+10	3.67E+10	3.79E+10	3.67E+10	3.79E+10

Table B.11 Existing annual loads from land-based sources for the Nawney (Subwatersheds 29, 30, 31, 32).

Source	Barren	Commercial	Cropland	High Density Residential	Livestock Access	Low Density Residential	Pasture	Water	Wetlands	Woodland
beaver	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.46E+09	0.00E+00	0.00E+00
beef	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
cats high residential	0.00E+00	0.00E+00	0.00E+00	1.47E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
cats low residential	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.43E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
deer	0.00E+00	7.51E+09	3.56E+12	1.36E+10	9.18E+10	2.74E+10	1.06E+12	0.00E+00	1.57E+12	2.98E+11
dogs high residential	0.00E+00	0.00E+00	0.00E+00	5.70E+12	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
dogs low residential	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.55E+12	0.00E+00	0.00E+00	0.00E+00	0.00E+00
duck	0.00E+00	4.56E+07	2.54E+09	4.26E+07	2.87E+08	7.91E+07	5.25E+08	0.00E+00	2.35E+09	1.98E+08
goose	0.00E+00	2.96E+10	1.65E+12	2.76E+10	1.86E+11	5.13E+10	3.40E+11	0.00E+00	1.52E+12	1.29E+11
gull	0.00E+00	7.73E+11	4.56E+13	1.03E+12	2.79E+12	1.44E+12	1.19E+13	0.00E+00	2.83E+13	3.58E+12
hog	0.00E+00	0.00E+00	2.11E+15	0.00E+00	0.00E+00	0.00E+00	1.17E+14	0.00E+00	0.00E+00	0.00E+00
horse	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.19E+13	0.00E+00	0.00E+00	0.00E+00
muskrat	0.00E+00	8.68E+10	4.50E+12	6.33E+10	2.69E+11	1.06E+11	1.50E+12	0.00E+00	1.38E+13	2.19E+12
raccoon	0.00E+00	8.32E+11	4.97E+13	1.28E+12	1.65E+12	1.53E+12	1.44E+13	0.00E+00	2.24E+13	4.06E+12
septic failure density	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.40E+13	0.00E+00	0.00E+00	0.00E+00	0.00E+00
sheep	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
straightpipe density	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.19E+13	0.00E+00	0.00E+00

Table B.12 Existing annual loads from direct-deposition sources for the Nawney (Reaches 29, 30, 31, 32).

Source	Annual Total Loads (cfu/yr)
beaver	2.46E+09
beef	0.00E+00
deer	3.37E+09
duck	2.55E+08
goose	1.09E+11
gull	2.56E+12
hog	0.00E+00
muskrat	1.11E+12
raccoon	2.45E+11
straightpipe density	1.19E+13

Table B.13 Current conditions of land applied fecal coliform load for West Neck Creek (Middle) by landuse (Subwatersheds 23, 24, 25, 26, 27, 28).

Landuse	Barren	Commercial	Cropland	High Density Residential	Livestock Access	Low Density Residential	Pasture	Wetlands	Woodland
January	3.67E+10	2.96E+10	6.86E+12	1.53E+12	1.16E+11	6.44E+12	1.23E+12	5.97E+12	1.86E+12
February	3.32E+10	2.68E+10	6.19E+12	1.38E+12	1.05E+11	5.73E+12	1.11E+12	5.39E+12	1.68E+12
March	3.67E+10	2.96E+10	6.86E+12	1.53E+12	1.16E+11	6.14E+12	1.23E+12	5.97E+12	1.86E+12
April	3.56E+10	2.87E+10	6.63E+12	1.48E+12	1.13E+11	5.85E+12	1.19E+12	5.78E+12	1.80E+12
May	3.67E+10	2.96E+10	6.86E+12	1.53E+12	1.16E+11	5.94E+12	1.23E+12	5.97E+12	1.86E+12
June	3.56E+10	2.87E+10	6.63E+12	1.48E+12	1.13E+11	5.65E+12	1.19E+12	5.78E+12	1.80E+12
July	3.67E+10	2.96E+10	6.86E+12	1.53E+12	1.16E+11	5.64E+12	1.23E+12	5.97E+12	1.86E+12
August	3.67E+10	2.96E+10	6.86E+12	1.53E+12	1.16E+11	5.64E+12	1.23E+12	5.97E+12	1.86E+12
September	3.56E+10	2.87E+10	6.63E+12	1.48E+12	1.13E+11	5.46E+12	1.19E+12	5.78E+12	1.80E+12
October	3.67E+10	2.96E+10	6.86E+12	1.53E+12	1.16E+11	5.54E+12	1.23E+12	5.97E+12	1.86E+12
November	3.56E+10	2.87E+10	6.63E+12	1.48E+12	1.13E+11	5.46E+12	1.19E+12	5.78E+12	1.80E+12
December	3.67E+10	2.96E+10	6.86E+12	1.53E+12	1.16E+11	6.04E+12	1.23E+12	5.97E+12	1.86E+12
Annual Total Loads (cfu/yr)	4.33E+11	3.49E+11	8.07E+13	1.80E+13	1.37E+12	6.95E+13	1.45E+13	7.03E+13	2.19E+13

Table B.14 Monthly, directly deposited fecal coliform loads in each reach of the West Neck Creek (Middle) (Reaches 23, 24, 25, 26, 27, 28).

Reach ID	Source Type	January	February	March	April	May	June
23	Human/Pet	2.96E+11	2.67E+11	2.96E+11	2.86E+11	2.96E+11	2.86E+11
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	4.12E+10	3.72E+10	4.12E+10	3.98E+10	4.12E+10	3.98E+10
24	Human/Pet	2.38E+11	2.15E+11	2.38E+11	2.31E+11	2.38E+11	2.31E+11
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	4.38E+10	3.96E+10	4.38E+10	4.24E+10	4.38E+10	4.24E+10
25	Human/Pet	3.80E+10	3.44E+10	3.80E+10	3.68E+10	3.80E+10	3.68E+10
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	5.71E+10	5.16E+10	5.71E+10	5.53E+10	5.71E+10	5.53E+10
26	Human/Pet	1.14E+12	1.03E+12	1.14E+12	1.10E+12	1.14E+12	1.10E+12
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	4.54E+10	4.10E+10	4.54E+10	4.39E+10	4.54E+10	4.39E+10
27	Human/Pet	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	8.44E+10	7.62E+10	8.44E+10	8.16E+10	8.44E+10	8.16E+10
28	Human/Pet	1.57E+09	1.42E+09	1.57E+09	1.52E+09	1.57E+09	1.52E+09
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	4.51E+10	4.07E+10	4.51E+10	4.36E+10	4.51E+10	4.36E+10
Reach ID	**Source Type**	**July**	**August**	**September**	**October**	**November**	**December**
23	Human/Pet	2.96E+11	2.96E+11	2.86E+11	2.96E+11	2.86E+11	2.96E+11
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	4.12E+10	4.12E+10	3.98E+10	4.12E+10	3.98E+10	4.12E+10
24	Human/Pet	2.38E+11	2.38E+11	2.31E+11	2.38E+11	2.31E+11	2.38E+11
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	4.38E+10	4.38E+10	4.24E+10	4.38E+10	4.24E+10	4.38E+10
25	Human/Pet	3.80E+10	3.80E+10	3.68E+10	3.80E+10	3.68E+10	3.80E+10
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	5.71E+10	5.71E+10	5.53E+10	5.71E+10	5.53E+10	5.71E+10
26	Human/Pet	1.14E+12	1.14E+12	1.10E+12	1.14E+12	1.10E+12	1.14E+12
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	4.54E+10	4.54E+10	4.39E+10	4.54E+10	4.39E+10	4.54E+10
27	Human/Pet	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	8.44E+10	8.44E+10	8.16E+10	8.44E+10	8.16E+10	8.44E+10
28	Human/Pet	1.57E+09	1.57E+09	1.52E+09	1.57E+09	1.52E+09	1.57E+09
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	4.51E+10	4.51E+10	4.36E+10	4.51E+10	4.36E+10	4.51E+10

Table B.15 Existing annual loads from land-based sources for the West Neck Creek (Middle) (Subwatersheds 23, 24, 25, 26, 27, 28).

Source	Barren	Commercial	Cropland	High Density Residential	Livestock Access	Low Density Residential	Pasture	Water	Wetlands	Woodland
beaver	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.87E+09	0.00E+00	0.00E+00
beef	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
cats high residential	0.00E+00	0.00E+00	0.00E+00	4.57E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
cats low residential	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.21E+08	0.00E+00	0.00E+00	0.00E+00	0.00E+00
deer	1.18E+10	1.78E+09	2.22E+12	8.20E+08	2.05E+10	5.68E+09	1.90E+11	0.00E+00	1.62E+12	6.64E+11
dogs high residential	0.00E+00	0.00E+00	0.00E+00	1.77E+13	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
dogs low residential	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.69E+13	0.00E+00	0.00E+00	0.00E+00	0.00E+00
duck	1.26E+07	7.58E+06	1.85E+09	3.41E+06	6.29E+07	1.61E+07	1.16E+08	0.00E+00	3.82E+09	3.74E+08
goose	8.20E+09	4.92E+09	1.20E+12	2.21E+09	4.08E+10	1.05E+10	7.53E+10	0.00E+00	2.48E+12	2.43E+11
gull	2.18E+11	1.46E+11	3.16E+13	9.85E+10	6.13E+11	3.18E+11	2.42E+12	0.00E+00	3.66E+13	7.56E+12
hog	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
horse	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.94E+12	0.00E+00	0.00E+00	0.00E+00
muskrat	1.04E+10	0.00E+00	1.41E+13	1.38E+10	3.31E+11	3.92E+10	1.09E+12	0.00E+00	6.01E+12	5.03E+12
raccoon	1.84E+11	1.97E+11	3.16E+13	1.57E+11	3.65E+11	3.48E+11	2.80E+12	0.00E+00	2.36E+13	8.36E+12
septic failure density	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.19E+13	0.00E+00	0.00E+00	0.00E+00	0.00E+00
sheep	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
straightpipe density	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.02E+13	0.00E+00	0.00E+00

Table B.16 Existing annual loads from direct-deposition sources for the West Neck Creek (Middle) (Reaches 23, 24, 25, 26, 27, 28).

Source	Annual Total Loads (cfu/yr)
beaver	2.87E+09
beef	0.00E+00
deer	2.41E+09
duck	2.60E+08
goose	1.11E+11
gull	2.14E+12
hog	0.00E+00
muskrat	1.31E+12
raccoon	1.74E+11
straightpipe density	2.02E+13

Table B.17 Current conditions of land applied fecal coliform load for West Neck Creek (Upper) by landuse (Subwatersheds 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 16).

Landuse	Barren	Commercial	Cropland	High Density Residential	Livestock Access	Low Density Residential	Pasture	Wetlands	Woodland
January	1.78E+12	3.85E+12	5.82E+12	3.14E+13	8.08E+11	1.59E+13	1.19E+13	9.60E+12	4.78E+12
February	1.60E+12	3.47E+12	5.25E+12	2.84E+13	7.30E+11	1.43E+13	1.08E+13	8.67E+12	4.32E+12
March	1.78E+12	3.85E+12	5.82E+12	3.14E+13	8.08E+11	1.58E+13	1.19E+13	9.60E+12	4.78E+12
April	1.72E+12	3.72E+12	5.63E+12	3.04E+13	7.82E+11	1.52E+13	1.15E+13	9.29E+12	4.62E+12
May	1.78E+12	3.85E+12	5.82E+12	3.14E+13	8.08E+11	1.56E+13	1.19E+13	9.60E+12	4.78E+12
June	1.72E+12	3.72E+12	5.63E+12	3.04E+13	7.82E+11	1.51E+13	1.15E+13	9.29E+12	4.62E+12
July	1.78E+12	3.85E+12	5.82E+12	3.14E+13	8.08E+11	1.55E+13	1.19E+13	9.60E+12	4.78E+12
August	1.78E+12	3.85E+12	5.82E+12	3.14E+13	8.08E+11	1.55E+13	1.19E+13	9.60E+12	4.78E+12
September	1.72E+12	3.72E+12	5.63E+12	3.04E+13	7.82E+11	1.50E+13	1.15E+13	9.29E+12	4.62E+12
October	1.78E+12	3.85E+12	5.82E+12	3.14E+13	8.08E+11	1.54E+13	1.19E+13	9.60E+12	4.78E+12
November	1.72E+12	3.72E+12	5.63E+12	3.04E+13	7.82E+11	1.50E+13	1.15E+13	9.29E+12	4.62E+12
December	1.78E+12	3.85E+12	5.82E+12	3.14E+13	8.08E+11	1.57E+13	1.19E+13	9.60E+12	4.78E+12
Annual Total Loads (cfu/yr)	2.09E+13	4.53E+13	6.85E+13	3.70E+14	9.52E+12	1.84E+14	1.40E+14	1.13E+14	5.63E+13

Table B.18 Monthly, directly deposited fecal coliform loads in each reach of the West Neck Creek (Upper) (Reaches 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22).

Reach ID	Source Type	January	February	March	April	May	June
10	Human/Pet	8.07E+11	7.29E+11	8.07E+11	7.81E+11	8.07E+11	7.81E+11
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	3.46E+10	3.12E+10	3.46E+10	3.35E+10	3.46E+10	3.35E+10
11	Human/Pet	3.27E+11	2.96E+11	3.27E+11	3.17E+11	3.27E+11	3.17E+11
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	2.12E+10	1.91E+10	2.12E+10	2.05E+10	2.12E+10	2.05E+10
12	Human/Pet	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	3.84E+10	3.46E+10	3.84E+10	3.71E+10	3.84E+10	3.71E+10
13	Human/Pet	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	3.39E+10	3.06E+10	3.39E+10	3.28E+10	3.39E+10	3.28E+10
14	Human/Pet	1.82E+12	1.64E+12	1.82E+12	1.76E+12	1.82E+12	1.76E+12
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	3.87E+10	3.50E+10	3.87E+10	3.75E+10	3.87E+10	3.75E+10
15	Human/Pet	4.89E+11	4.41E+11	4.89E+11	4.73E+11	4.89E+11	4.73E+11
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	3.10E+10	2.80E+10	3.10E+10	3.00E+10	3.10E+10	3.00E+10
16	Human/Pet	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	1.12E+11	1.02E+11	1.12E+11	1.09E+11	1.12E+11	1.09E+11
17	Human/Pet	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	6.84E+10	6.17E+10	6.84E+10	6.61E+10	6.84E+10	6.61E+10
18	Human/Pet	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	7.01E+10	6.33E+10	7.01E+10	6.79E+10	7.01E+10	6.79E+10
19	Human/Pet	3.41E+11	3.08E+11	3.41E+11	3.30E+11	3.41E+11	3.30E+11
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	4.94E+10	4.46E+10	4.94E+10	4.78E+10	4.94E+10	4.78E+10
20	Human/Pet	5.76E+08	5.20E+08	5.76E+08	5.57E+08	5.76E+08	5.57E+08
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	8.95E+09	8.09E+09	8.95E+09	8.66E+09	8.95E+09	8.66E+09
21	Human/Pet	5.58E+09	5.04E+09	5.58E+09	5.40E+09	5.58E+09	5.40E+09
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	7.30E+10	6.60E+10	7.30E+10	7.07E+10	7.30E+10	7.07E+10
22	Human/Pet	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	1.18E+11	1.07E+11	1.18E+11	1.14E+11	1.18E+11	1.14E+11

Table B.18 Monthly, directly deposited fecal coliform loads in each reach of the West Neck Creek (Upper) (Reaches 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22), (cont.).

Reach ID	Source Type	July	August	September	October	November	December
10	Human/Pet	8.07E+11	8.07E+11	7.81E+11	8.07E+11	7.81E+11	8.07E+11
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	3.46E+10	3.46E+10	3.35E+10	3.46E+10	3.35E+10	3.46E+10
11	Human/Pet	3.27E+11	3.27E+11	3.17E+11	3.27E+11	3.17E+11	3.27E+11
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	2.12E+10	2.12E+10	2.05E+10	2.12E+10	2.05E+10	2.12E+10
12	Human/Pet	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	3.84E+10	3.84E+10	3.71E+10	3.84E+10	3.71E+10	3.84E+10
13	Human/Pet	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	3.39E+10	3.39E+10	3.28E+10	3.39E+10	3.28E+10	3.39E+10
14	Human/Pet	1.82E+12	1.82E+12	1.76E+12	1.82E+12	1.76E+12	1.82E+12
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	3.87E+10	3.87E+10	3.75E+10	3.87E+10	3.75E+10	3.87E+10
15	Human/Pet	4.89E+11	4.89E+11	4.73E+11	4.89E+11	4.73E+11	4.89E+11
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	3.10E+10	3.10E+10	3.00E+10	3.10E+10	3.00E+10	3.10E+10
16	Human/Pet	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	1.12E+11	1.12E+11	1.09E+11	1.12E+11	1.09E+11	1.12E+11
17	Human/Pet	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	6.84E+10	6.84E+10	6.61E+10	6.84E+10	6.61E+10	6.84E+10
18	Human/Pet	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	7.01E+10	7.01E+10	6.79E+10	7.01E+10	6.79E+10	7.01E+10
19	Human/Pet	3.41E+11	3.41E+11	3.30E+11	3.41E+11	3.30E+11	3.41E+11
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	4.94E+10	4.94E+10	4.78E+10	4.94E+10	4.78E+10	4.94E+10
20	Human/Pet	5.76E+08	5.76E+08	5.57E+08	5.76E+08	5.57E+08	5.76E+08
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	8.95E+09	8.95E+09	8.66E+09	8.95E+09	8.66E+09	8.95E+09
21	Human/Pet	5.58E+09	5.58E+09	5.40E+09	5.58E+09	5.40E+09	5.58E+09
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	7.30E+10	7.30E+10	7.07E+10	7.30E+10	7.07E+10	7.30E+10
22	Human/Pet	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	1.18E+11	1.18E+11	1.14E+11	1.18E+11	1.14E+11	1.18E+11

Table B. 19 Existing annual loads from land-based sources for the West Neck Creek (Upper) (Subwatersheds 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22).

Source	Barren	Commercial	Cropland	High Density Residential	Livestock Access	Low Density Residential	Pasture	Water	Wetlands	Woodland
beaver	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.26E+09	0.00E+00	0.00E+00
beef	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
cats high residential	0.00E+00	0.00E+00	0.00E+00	8.26E+08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
cats low residential	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.47E+08	0.00E+00	0.00E+00	0.00E+00	0.00E+00
deer	1.86E+12	7.88E+11	6.79E+12	1.11E+11	4.81E+11	4.31E+12	4.03E+12	0.00E+00	6.80E+12	5.23E+12
dogs high residential	0.00E+00	0.00E+00	0.00E+00	3.20E+14	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
dogs low residential	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.55E+13	0.00E+00	0.00E+00	0.00E+00	0.00E+00
duck	5.56E+08	9.80E+08	1.64E+09	1.18E+09	4.03E+08	1.65E+09	4.31E+08	0.00E+00	2.93E+09	1.14E+09
goose	3.61E+11	6.35E+11	1.06E+12	7.63E+11	2.61E+11	1.07E+12	2.80E+11	0.00E+00	1.90E+12	7.39E+11
gull	8.88E+12	1.89E+13	2.82E+13	2.21E+13	4.52E+12	3.04E+13	1.06E+13	0.00E+00	4.33E+13	2.19E+13
hog	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
horse	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.11E+14	0.00E+00	0.00E+00	0.00E+00
muskrat	9.18E+11	3.25E+12	3.80E+12	4.12E+12	9.97E+11	6.01E+12	1.59E+12	0.00E+00	1.88E+13	4.85E+12
raccoon	8.89E+12	2.17E+13	2.86E+13	2.31E+13	3.25E+12	3.34E+13	1.25E+13	0.00E+00	4.22E+13	2.36E+13
septic failure density	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.33E+13	0.00E+00	0.00E+00	0.00E+00	0.00E+00
sheep	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
straightpipe density	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.46E+13	0.00E+00	0.00E+00

Table B.20 Existing annual loads from direct-deposition sources for the West Neck Creek (Upper) (Reaches 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22).

Source	Annual Total Loads (cfu/yr)
beaver	4.26E+09
beef	0.00E+00
deer	1.56E+10
duck	4.76E+08
goose	2.03E+11
gull	5.19E+12
hog	0.00E+00
muskrat	2.30E+12
raccoon	5.14E+11
straightpipe_density	4.46E+13